energies

MDPI

Article

Performance, Emission and Combustion Characteristics of a Diesel Engine Powered by Macadamia and Grapeseed Biodiesels

Abul Kalam Azad [1,*], Julian Adhikari [1], Pobitra Halder [2], Mohammad G. Rasul [3], Nur M. S. Hassan [4], Mohammad M. K. Khan [1], Salman Raza Naqvi [5] and Karthickeyan Viswanathan [6]

1 School of Engineering and Technology, Central Queensland University, Melbourne, VIC 3000, Australia; julianwinadhikari@gmail.com (J.A.); m.khan@cqu.edu.au (M.M.K.K.)
2 School of Engineering, RMIT University, 124 La Trobe Street, Melbourne, VIC 3000, Australia; pobitra.halder@gmail.com
3 School of Engineering and Technology, Central Queensland University, Rockhampton, QLD 4702, Australia; m.rasul@cqu.edu.au
4 School of Engineering and Technology, Central Queensland University, Cairns, QLD 4870, Australia; n.hassan@cqu.edu.au
5 School of Chemical and Materials Engineering, National University of Sciences and Technology, H-12, Islamabad 44000, Pakistan; salman.raza@scme.nust.edu.pk
6 Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore 641008, India; karthickeyanme.ice@gmail.com
* Correspondence: a.k.azad@cqu.edu.au or azad.cqu@gmail.com

Received: 29 March 2020; Accepted: 21 May 2020; Published: 31 May 2020

Abstract: Biodiesel is an alternative, eco-friendly and renewable source of energy. It can be produced from a wide range of feedstocks which can be grown in marginal land use. It has drawn more attention to the researchers. In this study, the oil extraction, biodiesel conversion, and physiochemical properties of Macadamia (*Macadamia integrifolia*) and Grapeseed (*Vitis vinifera*) biodiesels are presented. The experimental investigation of diesel engine performance, emissions and combustion characteristics were conducted using B5 (5% biodiesel and 95% diesel by volume) and B10 (10% biodiesel and 90% diesel by volume) blends. The engine performance parameters, such as brake power (BP), brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE) have been investigated in this experiment. The emission parameters, for example, carbon monoxide (CO), the ratio of CO_2/CO, nitrogen oxide (NO_x), hydrocarbon (HC), particulate matter (PM) have been measured during the experiment. Finally, the combustion parameters such as cylinder pressure (CP) were recorded, and heat release rate (HRR) was analysed and compared with that of diesel fuel. The study revealed that the Macadamia biodiesel performed better than Grapeseed biodiesel and behaved closely to that of diesel fuel. A significant reduction of engine emissions was found in the case of Macadamia biodiesel with a minimal reduction of engine performance. Further analysis of energy, exergy and tribological characteristics of the Macadamia biodiesel is recommended for assessing its feasibility for commercial application.

Keywords: biodiesel; macadamia biodiesel; grapeseed biodiesel; brake specific fuel consumption; brake thermal efficiency; CO; HC emission; NO_x emission; cylinder pressure; heat release rate

1. Introduction

The energy demand is growing faster than the population growth in the world. The total population which is overgrowing in recent decades is expected to be 10 billion people to reside in the globe by 2050. So, the demand for energy will increase substantially every year. In recent times, energy has become one of the most leading necessities for humanity. In order to sustainably fulfil the energy crisis, the world's growing population has required more energy for their survival. The increase in population, modernisation of the community, and improvement in lifestyle have been rising the energy demand. The growth in the energy sector from other sources will fulfil this demand [1]. Moreover, the increase in energy demand leads us towards finding an alternative source of renewable energy. With the growing concern for climate change and pollution, protecting the environment has become the prime focus of the developed countries. Therefore, renewable energy such as biodiesel has been considered as the preferred form of alternative energy, because it is eco-friendly and biodegradable, and it can be used commercially in the diesel engine. Biofuel has some advantageous characteristics over the normal diesel fuel as it has less toxicity, and a considerable reduction in sulfur oxides (SO_x) gases and has less carbon monoxide (CO) and polyaromatic hydrocarbons and has produced less smoke and particulate matter.

Biodiesel, as a renewable energy source, has drawn the attention of many researchers because it is considered to be one of the potential substitutes for diesel fuel [2,3]. It is a long-chain fatty acids inclusion of mono-alkyl esters refined from vegetable oil or animal fats which meet the requirements of the American Society for Testing and Materials ASTM D6751 standards [4]. Biodiesel can be made from a wide range of feedstocks such as biomass [5] and other raw materials such as starch, simple sugars and lignocellulose [6–8]. The biofuels have been extracted from edible vegetable oil, such as cottonseed oil and sunflower oil, which are categorised as the first-generation biofuel. The second-generation biofuels are extracted from non-edible vegetable oils, for example, Jatropha oil, Karanja oil, Grapeseed oil, *Calophyllum inophyllum* [9,10], moringa oil [11], and microalgae as the third generation [12–14]. The extreme uses of biofuels from edible vegetable oils can cause an increase in food price, that leads to possible devastation and starvation [15]. Recent research has concentrated on non-edible or second-generation feedstocks instead of the first-generation feedstocks [16].

Literature reported that various non-edible vegetable oil feedstocks are one of the sources for biodiesel production [17–20]. For instance, Abhilash et al. [21] noticed that *Jatropha carcass* is one of the most dominant and available sources of biofuel. It belongs to the Euphobiaceae family, with a usual plant height of 5 to 7m [22] and it can be planted in drought and degraded or surplus agricultural lands [23]. As this is a tropical plant, it requires an average rainfall of 250 mm to 1200 mm and can survive about 30 to 50 years and produces seed after one only year of cultivation [22]. The seed oil content is around 43 to 59% [22]. These studies revealed that Jatropha carcass is a promising energy crop for large-scale production of biodiesel, and researchers have undertaken several studies to obtain a good insight into biofuel production [24].

The study of the physiochemical properties of biodiesel is crucial to be considered in the experiments to see how close the properties are in comparison with the regular diesel fuel. For example, Ali et al. [25] investigated the effect of the physicochemical properties of biofuels. The result showed that biodiesel has higher kinematic viscosity which results in poor fuel atomisation into the engine cylinder. The higher density of biodiesel leads to higher fuel consumption and an increase in mass flow rate during fuel injection. Some other important fuel properties such as pour point of biodiesel can be used to identify the performance at low temperatures, and the cloud point helps in understanding the performance of biodiesel at higher temperatures.

Likewise, Miri et al. [6] examined the effects of physicochemical properties that are found in almost all biodiesels. They stated that the flashpoint of any oil can be referred to as the lowest temperature at which the oil starts to vaporise when the ignition is commenced. Again, the study revealed that any oil which has a higher flash point could be considered safe to store the fuel. This can lead to avoiding the undesirable ignition of the fuel during the combustion process [6].

The conversion of bio-oil to biodiesel is an important process to maintain the quality of the fuel. According to the literature, transesterification is one of the widely used processes for biodiesel conversion. For instance, Nisar et al. [26] considered the calcinated waste bones as a heterogeneous catalyst in the transesterification process for Jatropha oil. During the experiments, potassium hydroxide was used as a catalyst derived from animal bones in the production yield of 96.01%. In addition, Eloka-Eboka and Inambao [27] performed an analysis combining Jatropha and Moringa oil and confirmed that the technique of in-situ and ex-situ hybridisation could appear as an increase in the production of biodiesel. Furthermore, they ensured that this technique could produce improved biodiesel. The use of biodiesel in a diesel engine is crucial to justify the suitability of the fuel.

The modern diesel engines have the capability of running on bio-diesel unmodified, and most of the companies have properly stated that engine warranties will not be invalid using biodiesel blends [24]. It has been documented that an unmodified diesel engine will produce slightly less power and torque running with biodiesel. Some researchers used Karanja oil in their experiments. For example, Agarwal [28] experimented on a diesel engine varying the fuel injection pressure and fuel injection timing using Karanja oil. In comparison to mineral diesel, a higher brake specific fuel consumption from Karanja oil was produced due to the lower calorific value of the biodiesel [28]. In another experiment, Sahoo et al. [29] used blends of Jatropha oil on a diesel engine varying the engine speed from 1200 rpm to 2100 rpm. The experimental results of the engine performance and emission using Jatropha oil were compared with the regular diesel fuel. The blend JB20 (a blend of 20% Jatropha biodiesel and 80% mineral diesel) at a lower speed of 1200 rpm resulted in an insignificant difference in the power generation. As the speed was increased gradually from 1200 rpm, an increase in power was noticed. Additionally, with the increase in the percentage of Jatropha blends, the brake specific energy consumption (BSEC) was increased [29]. With regards to the emission produced from using Jatropha, Sahoo et al. [30] reported a reduction in carbon monoxide and hydrocarbon, however, an increase in nitrogen oxide was found in their study which is not desirable.

In addition, Dhar et al. [31] conducted an experiment using Neem oil with its varied blends in a single-cylinder and four-stroke diesel engine. Engine performance with the Neem oil and its blends showed an increase of brake specific fuel consumption (BSFC) in comparison with the mineral diesel. With the increase in the percentage of blends of Neem oil, the brake thermal efficiency (BTE) showed a slight decrease. Correspondingly, the emission of CO was observed to be almost the same as mineral diesel. On the other hand, a higher NO_x emission was reported, which is due to the higher contents of oxygen of biodiesel [31].

Furthermore, Nalgundwar et al. [32] performed an experimental study in a single-cylinder diesel engine by using a twin blend of biodiesel (Palm oil, Jatropha oil, and mineral diesel). They found that the lower blend of biodiesel D90PB5JB5 (diesel 90%, Palm oil 5% and Jatropha oil 5%) demonstrated better capability to reduce emission compared to other blends. Again, they confirmed that the lower viscosity and a higher calorific value leads to an increase in brake power [32,33]. Due to the lower calorific value of biodiesel, the reduction in the BSFC results in more fuel consumption with an increase of blend percentage. The calorific value and the oxygen content in the fuel alter the BTE. A decrease in BTE was noticed with the use of a higher blend of biodiesel. From the emission analysis, a reduced exhaust temperature was noticed in comparison with the mineral diesel. Nalgundwar et al. [32] also confirmed that the exhaust gas temperature was inversely dependent on combustion efficiency. The higher content of oxygen in biodiesel improved the combustion that would result in lower carbon monoxide emissions.

On the contrary, the higher viscosity and density possessed in biodiesel can lead to incomplete combustion [32]. Thus, with the increase in the content of biodiesel in the blends, an emission with higher carbon monoxide was noticed [32,34]. The lower biodiesel blends produced a noticeable carbon monoxide from the exhaust gas outlet. The proper harvesting techniques and processing system also play an important role in producing high-quality biodiesel. Furthermore, the government and farmers in developing countries might be much interested in farming edible oil vegetable plants among these non-edible oil feedstocks to improve the socio-economic aspects of sustainable biofuels [35,36].

Literature reported different feedstocks for biodiesel production and applications in diesel engines. The study identified potential feedstocks such as macadamia and grapeseed for further comparative analysis due to limited studies on engine performance and emission being found for those feedstocks. For example, Venkatesan et al. [37] evaluated biodiesel production from grapeseed oil using the surface methodology and found a 97.7% conversion yield. Chelladorai et al. [38] experimented on the effect of hydrogen induction with grapeseed oil in a CI engine and identified the dual-fuel improves BTE and reduces emissions. In addition, Vedagiri et al. [39] investigated the effect of a different engine chamber on engine characteristics using nano-additives blends with grapeseed biodiesel. They identified the combustion chamber shape has a direct impact on performance and noted 13.2% less NO_x emissions [40]. Furthermore, Praveena et al. [41] studied the effect of exhaust gas recirculation (ECR) with nano-emulsive blends of grapeseed biodiesel and found a NO_x emission reduction, which is expected. On the other hand, a few research groups investigated many feedstocks including macadamia biodiesel [42,43]. For example, Azad et al. [44] conducted a study on the physiochemical fuel properties of macadamia biodiesel. This research team also conducted a preliminary experiment on a diesel engine using this biodiesel to assess the sustainability of this fuel as an alternative fuel. Additionally, this study assessed the different potential of this biodiesel as an alternative fuel for automobiles in Australia. Currently, only 10% renewable fuel from other biodiesel sources is mixed with petroleum diesel commercially in Australia. In addition, the experimental studies on engine performance and various emission parameters were summarised from recent literature [45,46].

The research identified that an inadequate study is available in the literature on the comparative analysis of engine performance and emissions using Macadamia and Grapeseed biodiesel on a diesel engine. Therefore, there is a need to perform an experimental study on diesel engine performance and emissions using B5 (5% biodiesel and 95% diesel by volume) and B10 (10% biodiesel and 90% diesel by volume) blends. This study considered the engine performance parameters such as BP, BSFC, and BTE for the experimental analysis using multi-stage fuel injection with full engine load condition by varying speeds from 1200 rpm to 2400 rpm. The emission parameters such as CO, NO_x, HC, PM and the ratio of CO_2/CO emissions were measured and compared with the regular diesel fuel. In addition, cylinder pressure and the heat release rate have been analysed. The results of the proposed study shall provide valuable information and necessary data which would predict a significant reduction of emissions for the proposed biodiesels.

2. Materials and Methods

2.1. Biodiesel Preparation

In the current study, crude Grapeseed and Macadamia oil were extracted from the kernel by the solvent extraction method using n-hexane as a solvent. The seed has been crushed to the approximate particle size of 0.25 mm before oil extraction. The crude oil was converted into biodiesel via transesterification reaction [47]. The standard transesterification reaction was performed at 60 °C reaction temperature for 1-h reaction time, keeping the molar ratio of oil and methanol at 1:6 with 1% KOH as the catalyst. The mixture was stirred continuously at 750 rpm using a magnetic stirrer and heater (C-MAG HS7, IKA-Werke GmbH & Co. KG, Germany). The glycerin was separated into three different stages for biodiesel production. The unreacted methanol was removed by heating at 80 °C for 1 h. The remaining unreacted catalyst was removed by washing using demineralised (DM) water. Finally, the pure biodiesel was dried at 110 °C for 45 min to remove moisture and residual water particles. All the chemicals used in this study were obtained from Chem-supply. A gas chromatography (GC-2010 SHIMADZU, Kyoto, Japan) was used to identify the fatty acid methyl esters (FAMEs) in biodiesel following the AOCS Ce 1a-13 standard method. Table 1 shows the percentage of FAMEs in each of the biodiesels. As can be seen from the table, the Macadamia biodiesel contains 22 fatty acids, whereas Grapeseed biodiesel comprises 8 fatty acids. In the case of Macadamia biodiesel, oleic acid (C18:1) shared the maximum percentage of 61.09% followed by palmitoleic acid (C16:1) 15.39% and palmitic acid (C16:0) 8.25%. On the contrary, major fatty acids in Grapeseed biodiesel are linoleic acid (C18:2) 69.1%, oleic acid (C18:1) 19%, palmitic acid (C16:0) 6.9% and stearic acid (C18:0) 4% [44]. The study identified 96.58% and 100% methyl esters in Macadamia and Grapeseed biodiesel, respectively. The physiochemical fuel properties of the biodiesels were measured according to the American Society for Testing and Materials (ASTM) standards and compared with diesel as presented in Table 2. For this study, total biodiesel produced about 5 letters for engine testing due to the four-cylinder 3.32 letter engine setup. The biodiesel blends were prepared by mixing biodiesel and diesel in a volume ratio of 5:95 (B5) and 10:90 (B10) for each of the biodiesels.

Table 1. Fatty acid methyl esters (FAMEs) composition of the biodiesels measured by gas chromatography (GC) according to the ISO 11024 standard.

Fatty Acid Name	Lipid	Relative Contents (% vol.) in Biodiesel	
		Macadamia	Grapeseed
Lauric acid	C12:0	0.06	-
Myristic acid	C14:0	0.58	0.2
Tetradecenoic	C14:1	-	-
Pentadecylic acid	C15:0	-	-
Ginkgolic acid	C15:1	-	-
Palmitic acid	C16:0	8.25	6.9
Palmitoleic acid	C16:1	15.39	0.2
Margaric acid	C17:0	0.03	-
Ginkgolic acid	C17:1	0.08	-
Stearic acid	C18:0	3.55	4
Oleic acid	C18:1	61.09	19
Linoleic acid	C18:2	1.86	69.1
Linolenic acid	C18:3	0.11	0.3
Arachidic acid	C20:0	2.94	0.3
Eicosenoic acid	C20:1	2.55	-
Eicosadienoic	C20:2	0.06	-
Eicosatrienoic	C20:3	0.03	-
Eicosapentaenoic	C20:5	0.97	-
Behenic acid	C22:0	0.04	-
Erucic acid	C22:1	0.16	-
Gadolenic acid	C22:2	0.13	-
Docosahexaenoic	C22:6	0.02	-
Tricosylic acid	C23:0	0.06	-
Lignoceric acid	C24:0	0.08	-
Nervonic acid	C24:1	0.13	-

Table 2 illustrates the comparison of the physicochemical fuel properties of the Grapeseed and Macadamia biodiesels with other biodiesels using the ASTM standards from the literature [48]. The Macadamia and Grapeseed biodiesel were found within the range of standard limits in comparison to other biodiesels [49]. The study used the corresponding ASTM standard testing methods for analyzing the fuel properties as shown in Table 2. A higher density and viscosity of the Macadamia and Grapeseed biodiesels were found compared to the standard diesel, however, these properties are within the acceptable range of other biodiesels such as Kesambi, Simarouba, Mandarin and Apricot. In addition, higher values of cetane number of Macadamia and Grapeseed biodiesels and other biodiesels attributed to a higher saturated fatty acid composition. The study found a slightly lower calorific value of the biodiesels compared to diesel because of the higher saturated fatty acid composition as reported in the literature. In addition, the Macadamia biodiesel showed a better flashpoint as compared to other biodiesels. The Macadamia biodiesel offered a low acid value as compared to other biodiesels which showed its effectiveness towards loss corrosion [50,51].

Table 2. Physicochemical fuel properties of the biodiesels.

Property Specification	Unit	Grapeseed Biodiesel	Macadamia Biodiesel	Kesambi Biodiesel [52]	Simarouba Biodiesel [53]	Mandarin Biodiesel [47]	Apricot Biodiesel [54]	Diesel	Standard Methods
Density at 15 °C	kg/m^3	881	868	875.6	862	866	879.4	832	ASTM D1298
Viscosity at 40 °C	mm^2/s	4.13	4.57	4.71	3.1	4.10	4.21	4.10	ASTM D445
Cetane number	-	48	57.5	-	56.8	44	49.87	44	ASTM D613
Calorific value	MJ/kg	39.79	39.98	42.27	40.32	45.66	38.30	45.67	ASTM D240
Cold filter plugging point	°C	−6	−4	4	-	−7.3	-	−3	ASTM D6371
Flash point	°C	175	135	173	178	60	170	60	ASTM D93
Cloud point	°C	−2	6	5	17	−8.6	−4	−8.6	ASTM D2500
Pour point	°C	−6	−3	4	14	−15	−8	−15	ASTM D97
Iodine number	g/100 g	138	76.44	-	-	106.21	100.7	-	ASTM D1959
Acid value	mgKOH/g	0.27	0.15	-	0.4	0.22	0.08	0.5	ASTM D664
Oxygen content	%	11.18	11.71	-	-	-	-	0	-

2.2. Experimental Setup for Engine Performance and Emission Measurement

Figure 1 shows the schematic diagram of the experimental setup used for the analysis of combustion, engine performance, and emission. A 4-cylinder (98 × 110 mm) diesel engine (Kubota V3300) with multi-stage fuel injection facilities was employed in the current study. The total displacement, rated output power and rated torque of the engine were 3.318 L, 53.9 kW at 2600 rpm and 230 N.m at 1400 rpm, respectively. The experiment was performed for an engine speed between 1200 rpm and 2400 rpm at full load conditions. The cylinder pressure and crank angle data were measured by a piezoelectric transducer which was equipped on the head of the cylinder. The heat release rate varies with a crank angle that provides information on ignition delay, start, end and duration of combustion, which can be estimated by the following equation:

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1} \times P \times \frac{dV}{d\theta} + \frac{1}{\gamma - 1} \times V \times \frac{dP}{d\theta} \quad (\mathrm{J/CA}) \tag{1}$$

where $dQ/d\theta$ indicates the heat release rate in J/°CA, P refers cylinder pressure in N.m, V represents cylinder volume in m^3, γ is the specific heat constant, and θ denotes the engine crank angle °CA. The exhaust gas such as carbon-mono-oxide (CO), the ratio of CO_2/CO, hydrocarbon (HC), and nitrogen oxide (NO_x) was identified using an exhaust gas analyser. The particulate matter (PM) was measured using the MAHA MPM-4M particulate measurement device, which is suitable for particle sizes of <100 nm to >10 microns. The PM meter has been installed along with a probe to the exhaust pipe for real-time measurement of DPM concentration, including total carbon and elemental carbon. This device is widely used in the mining industry and non-road laboratory experiments.

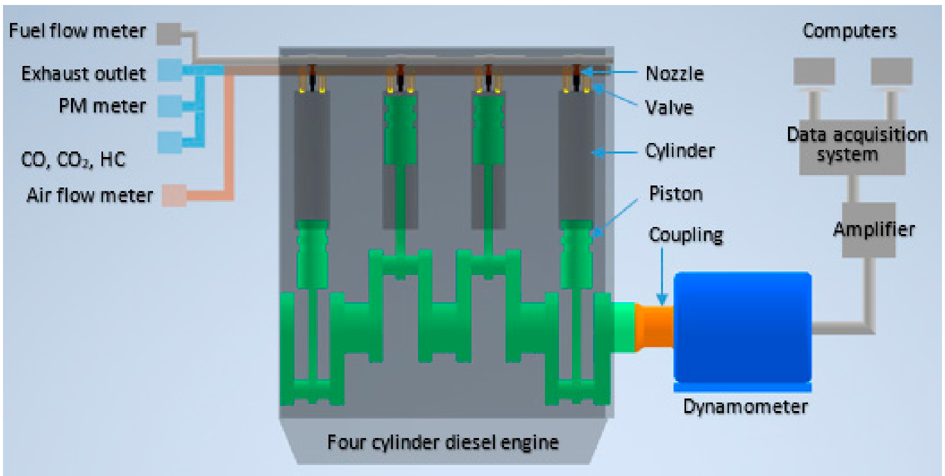

Figure 1. Schematic diagram of the experimental setup.

3. Results and Discussions

3.1. Engine Performance Analysis

3.1.1. Brake Power (BP)

Figure 2 illustrates the reduction in brake power using biodiesel blends in comparison to that of diesel for the engine speed ranging from 1200 rpm to 2400 rpm. It can be seen from the figure that all the blends tend to have a lower brake power than diesel. The increase of biodiesel blend resulted in a reduction in BP due to the lower heating value of the biodiesel compared to diesel as agreed by Ong et al. [55]. In addition, the higher density and viscosity of the biodiesel could be the reason for poor atomisation, vaporisation and mixing of the fuel droplets with air during combustion can lead the reduction of BP [25,56]. The higher viscosity of the fuel can cause poor combustion performance which results in lower BP and unwanted pollutions [57,58]. Figure 2 illustrates that the reduction of BP for Macadamia B5 was about 0.5% to 3% whereas for B10 it was about 1.5% to 4% compared to diesel. The *t*-test has been performed in this study where equal variances are assumed with a 95% confidence level and 5% significance level for the statistical analysis. In addition, there are two important conditions (a) statistically significant when p-value < 0.05) and (b) statistically insignificant when p-value > 0.05 that have been considered for interpretation of the results. The study found insignificant BP variation (p-value $= 0.443$) in a comparison between B5 and B10 Macadamia biodiesel blends. On the contrary, the Grapeseed B5 blend showed better BP output compared to that of the B10 blend. The Grapeseed B5 blend reduced the BP by 1.5% to 6.5% whereas the B10 blend reduced by 2 to 8% compared to diesel throughout the speed range. All the biodiesel blends had the lowest percentage of reduction in brake power at 1400 rpm because of the rated torque generating capability of the engine at that speed. However, a further increase in engine speed reduced the brake power output for all the biodiesel blends. From the *t*-test, the p-value of 0.098 shows the insignificant BP variation within the speed range for B5 and B10 Grapeseed blends.

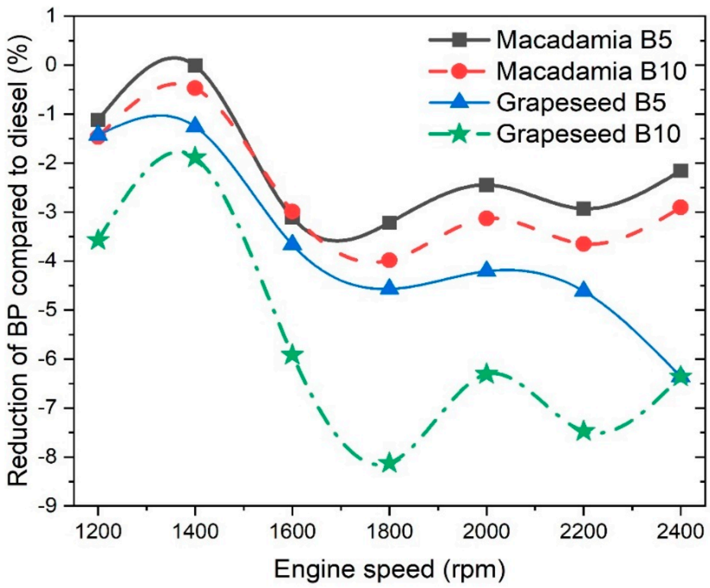

Figure 2. Comparison of brake power (BP) reduction using B5 and B10 biodiesel blends.

In comparison between Grapeseed and Macadamia biodiesels, Macadamia blends show better performance compared to Grapeseed blends due to some of its distinguished fuel properties [59]. For instance, the lower density, higher calorific value, higher certain number and iodine numbers of the Macadamia biodiesel compared to Grapeseed biodiesel as shown in Table 2. Although Macadamia blends have slightly higher viscosity compared to Grapeseed, it has a lower density, higher calorific value as well as higher oxygen content leading to better combustion and improvement in brake power [57]. The higher certain number of Macadamia blends implies better combustion efficiency by shortening ignition delay and prolonging combustion duration. Similar reasons have been reported in the literature [60]. Furthermore, the higher iodine number of Grapeseed implies a higher degree of unsaturation of the fuel, which indicates a greater number of double bonds present in the carbon chain leads to poor combustion performance compared to Macadamia biodiesel. The statistical *t*-test indicates the insignificant variation of BP (p-value = 0.078) between Macadamia and Grapeseed B5 blends, however, significant variation of BP ((p-value = 0.008)) has been noted for B10 blends between Macadamia and Grapeseed biodiesel.

3.1.2. Brake Specific Fuel Consumption (BSFC)

BSFC depends on the BP generation in the engine at a specific engine speed and the mass of fuel flow at that speed [18]. Figure 3 shows the variation of percentage in BSFC using biodiesel blends with respect to diesel at engine speeds between 1200 rpm and 2400 rpm. It can be observed from the figure that the BSFC for all the biodiesel blends increases when compared to that of diesel fuel. The high BSFC in the case of biodiesel blends was due to the lower calorific value of the biodiesel as shown in Table 2. The fuel having a lower calorific value, requires a greater amount of fuel to be introduced into the cylinder to produce the same amount of power compared with the higher calorific value fuel [57]. The percentage increase of BSFC using the Macadamia B10 blend was about 3 to 11% at various engine speeds, and it was about 2 to 8.5% using the Macadamia B5 blend. Grapeseed B10 blend, having higher biodiesel in the blend has the highest increment in BSFC among all other biodiesel blends used in this investigation. In addition to this, the BSFC of Grapeseed B10 blend varies significantly when compared to that of the Grapeseed B5 blend. Azad and Rasul [61] also noted the similar increasing trend of BSFC with the increase in biodiesel percentage into the blend. As the calorific value in biodiesel is lower than diesel, the addition of more biodiesel in the blend reduces the gross calorific value of the blend, which results in higher BSFC [62]. It can also be seen from the figure that the maximum BSFC value was observed at 1200 rpm for all the biodiesel blends. On the other hand, the lowest BSFC value was noted at an engine speed of 2400 rpm for all the blends.

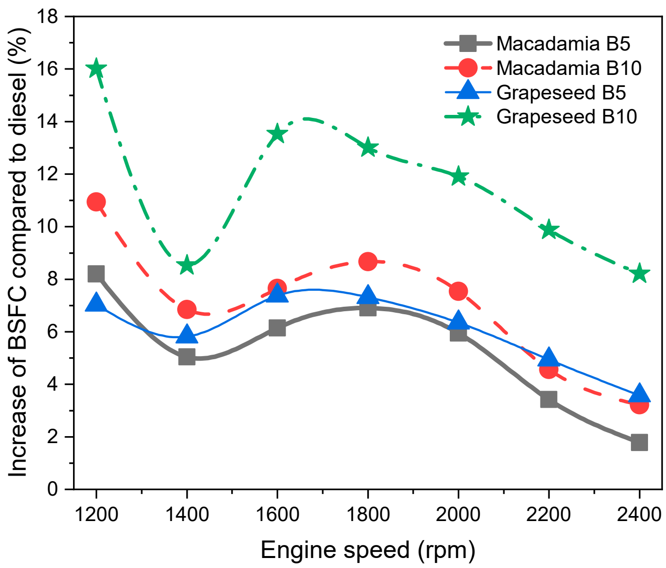

Figure 3. Comparison of the brake specific fuel consumption (BSFC) increase using B5 and B10 biodiesel blends.

The *t*-test has identified the statistically significant variation of BSFC for Grapeseed B5 and B10 (p-value = 0.001) blends; Macadamia B10 and Grapeseed B10 blends (p-value = 0.009), respectively.

On the other hand, the variation of BSFC is statistically insignificant because of p-value = 0.202 for B5 vs. B10 Macadamia biodiesel; p-value = 0.483 between Macadamia B5 and Grapeseed B5 blends, respectively.

3.1.3. Brake Thermal Efficiency (BTE)

The BTE is considered one of the key aspects for the evaluation of fuel performance when used in a diesel engine [25]. Figure 4 illustrates the decrease in BTE for biodiesel blends compared to that of diesel fuel at an engine speed ranging from 1200 rpm to 2400 rpm. The figure also shows that the BTE decreases for all biodiesel blends when compared with diesel. This may be due to the lower calorific value, higher density and viscosity of all the biodiesel blends compared to diesel. Higher density and viscosity of biodiesel blends cause poor vaporisation and atomisation of fuel, which results in improper air-fuel mixture due to the formation of large droplets as agreed by the literature [63,64]. Biodiesel B10 blend exhibited a higher decrease in BTE compared to B5 for both Macadamia and Grapeseed biodiesels because the higher kinematic viscosity of B10 than that of B5 increased the fuel consumption and extended the ignition delay. In the case of the Macadamia B5 blend, the decrease in the percentage of BTE for an engine speed range between 1200 rpm and 2400 rpm was about 2 to 7%, and for the Macadamia B10 blend it was 2 to 9%. The Grapeseed B5 blend and Grapeseed B10 blend resulted in a reduction of approximately 3 to 6% and 6 to 12.5% in BTE when compared to that for diesel fuel. The similar results also identified by the t-test that the statistically significant variation of BTE indicated by the p-value of 0.008 and 0.028 for Grapeseed B5 vs. B10 and B10 Macadamia vs. Grapeseed blends, respectively. Macadamia biodiesel blends showed better BTE compared to Grapeseed biodiesel blends due to the higher cetane number of Macadamia than Grapeseed biodiesel. The BTE of biodiesel blends tends to increase with the engine speed and reaches the maximum BTE value at 2400 rpm for all the biodiesel blends. The statistical analysis summaries show the BET variations are statistically insignificant, which is indicated by the p-value of 0.391 and 0.367 for Macadamia B5 vs. B10 and Macadamia vs. Grapeseed B5, respectively.

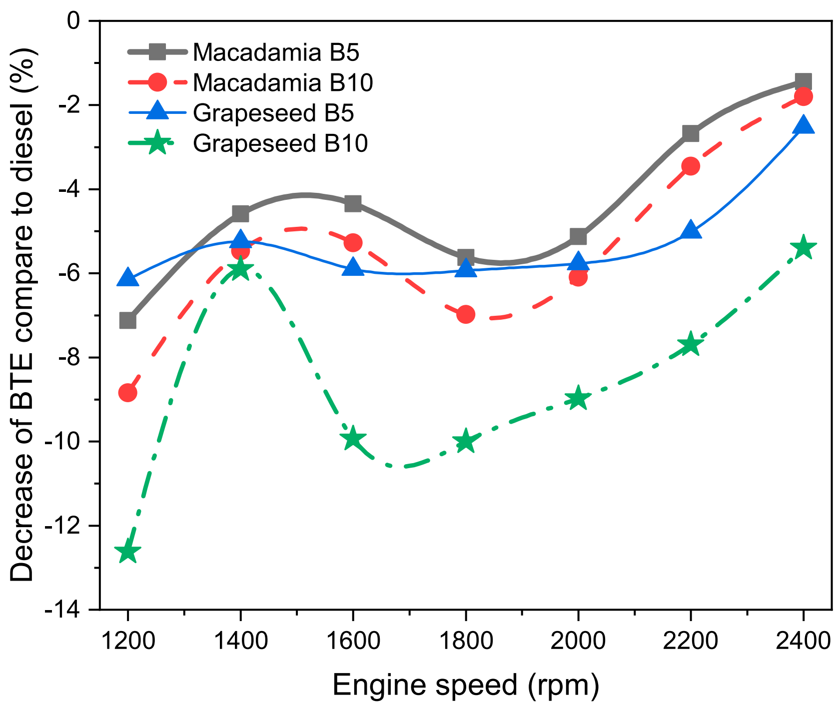

Figure 4. Effect of B5 and B10 biodiesel blends on brake thermal efficiency BTE compared to diesel.

3.2. Emission Analysis

3.2.1. Carbon-Mono-Oxide (CO) Emission

Figure 5 represents the variation in CO emission from different biodiesel blends in comparison to diesel at engine speeds between 1200 rpm and 2400 rpm. From the figure, it can be found that all the biodiesel blends investigated in this study reduced the CO emission when compared with diesel fuel. This emission reduction happened due to the higher content of oxygen and higher cetane number in biodiesel compared to that of diesel fuel [57]. The higher oxygen content in biodiesel could enhance the combustion of the fuel in the combustion chamber [65]. In general, the B10 biodiesel blends resulted in a higher reduction in CO emission than B5 blends for both Macadamia and Grapeseed biodiesel blends. The increase of biodiesel percentage in blends indicates the increase of oxygen content in the blends, which ensures the complete combustion of fuel and reduction of CO emissions.

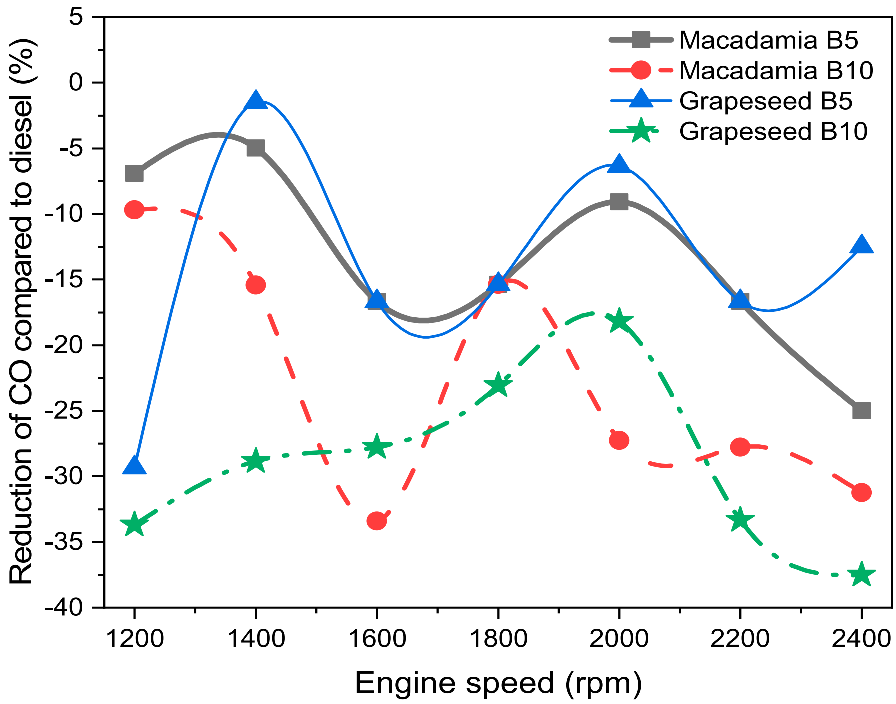

Figure 5. Reduction of carbon-mono-oxide (CO) emission using B5 and B10 biodiesel blends compared to diesel.

The Macadamia B5 blend showed a CO emission reduction of 7 to 25% whereas, the Macadamia B10 blend showed a further reduction with a value of 10 to 34%. In the case of Grapeseed biodiesel blends, B10 resulted in about 12 to 30% reduction in CO emission, while B5 caused about 17 to 34% reduction. The CO reduction is statistically significant for both Macadamia and Grapeseed blends as indicated by the p-value of 0.047 and 0.004 from the t-test, respectively. This result is in agreement with the previous works published in the literature, where the authors reported an approximately 8.6 to 40% reduction in CO emission with biodiesel [57]. The highest reduction in CO emission using the Macadamia B5 blend was noted at 2400 rpm and for the Macadamia B10 blend it was at 1600 rpm. The Grapeseed B5 blend showed maximum reduction at the lowest engine speed, whereas the Grapeseed B10 blend showed it at the highest engine speed. Besides, the comparison between B5 blends of Macadamia vs. Grapeseed and B10 blends of Macadamia vs. Grapeseed CO reduction shows it is statistically insignificant due to a p-value of 0.924 and 0.196, respectively.

3.2.2. Balancing of CO_2/CO Ratio

Figure 6 demonstrates the variation in CO_2/CO ratio of Macadamia and Grapeseed biodiesel blends in comparison to diesel at engine speeds between 1200 rpm and 2400 rpm. In the case of Macadamia biodiesel blends, the value of CO_2/CO ratio at 1200 rpm was much lower compared to diesel and Grapeseed biodiesel blends. In contrast, the CO_2/CO ratio was found to increase for Grapeseed biodiesel blends B10 and B5 at 1200 rpm. The lower emission in the case of Macadamia biodiesel blends could be due to the higher cetane number of Macadamia biodiesel, which reduces the ignition delay and improves the combustion. In addition, with the increase in engine speed, the ratio was seen to increase to close that of diesel. The higher CO_2/CO ratio for Grapeseed biodiesel at the engine speed of 1200 rpm was due to the improper fuel atomisation. Apart from this, the value of the CO_2/CO ratio was reduced with the increase in the engine speed for Grapeseed biodiesel blends. This may be due to the increase in temperature as a result of higher fuel consumption at the higher engine speed. However, the opposite trend was observed in the case of Macadamia biodiesel blends.

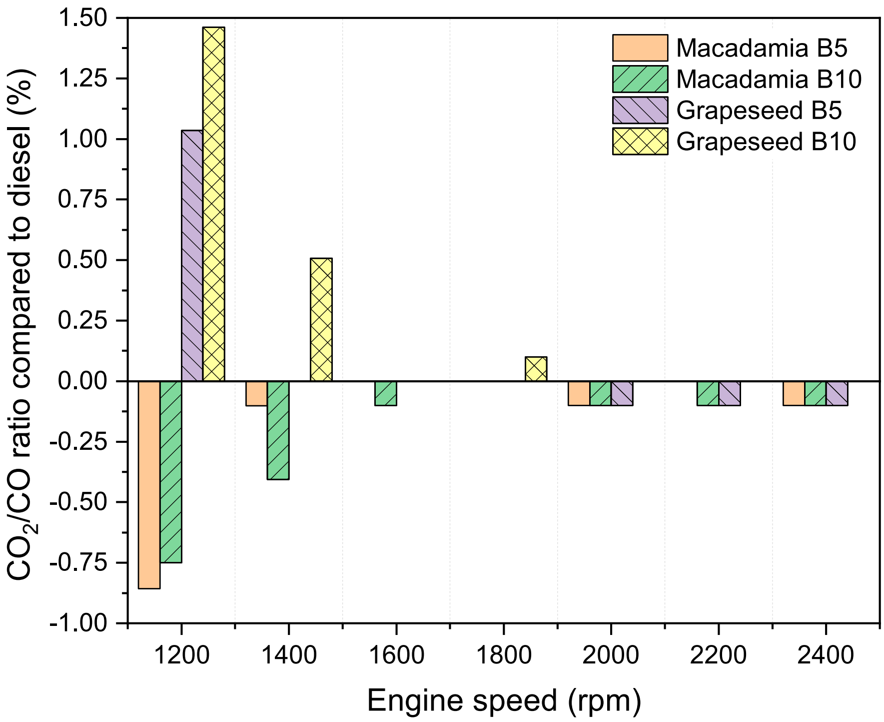

Figure 6. Variation of CO_2/CO ratio balancing with the variation of engine speed.

3.2.3. Hydrocarbon (HC) Emission

Figure 7 reveals the reduction in hydrocarbon emission from biodiesel blends. The reduction in HC emission using the Macadamia B5 blend was about 5 to 10%, whereas the use of the Macadamia B10 blend reduced the HC emission by 4 to 17%. Grapeseed B5 and B10 resulted in approximately 32 to 60% and 30 to 50% reduction in HC emission, respectively. The reason behind the reduction in HC emissions for biodiesel blends could be due to the presence of a higher percentage of oxygen in biodiesel, which enhances the oxidation reaction and burns the HC [66,67]. Additionally, the higher cetane number present in biodiesel decreases the combustion delay and ultimately burns the higher amount of HC in the cylinder [57]. Li et al. [57] also observed a reduction in HC emissions using biodiesel when compared with diesel fuel. The Grapeseed B5 blend demonstrated the maximum reduction in HC emissions and found it to be increased with the increase in engine speed. When the HC emission from Grapeseed blends was compared with that from Macadamia blends, Grapeseed blends exhibited a higher percentage of HC emission reduction.

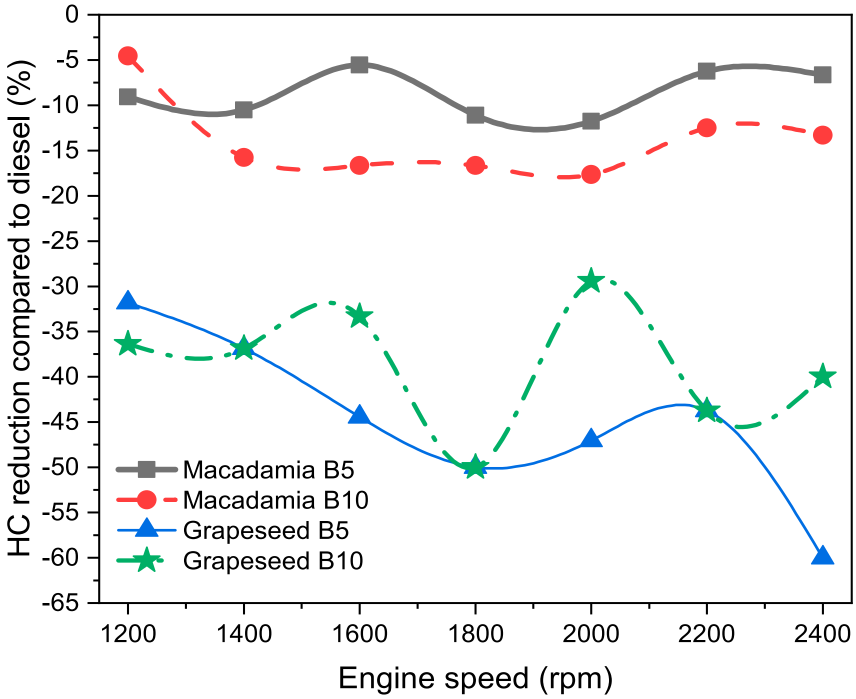

Figure 7. Hydrocarbon (HC) emission reduction compared to diesel using B5 and B10 biodiesel blends.

The *t*-test indicates HC reductions are statistically significant (p-value < 0.05) as indicated by the p-value of 0.022 for Macadamia B5 vs. B10; the p-value of 0.0001 for both B5 and B10 blends of Macadamia vs. Grapeseed. However, HC reduction is insignificant (p-value = 0.163) for Grapeseed B5 vs. B10 blends where the p-value was > 0.05.

3.2.4. Particulate Matters (PM) Emission

Figure 8 presents the percentage reduction of PM emission for biodiesel blends with respect to diesel at various engine speeds between 1200 rpm and 2400 rpm. The PM emission was found reduced for all the biodiesel blends. The presence of a higher amount of oxygen in biodiesel leads to the complete combustion of fuel and reduces the PM emission during combustion [68,69]. The percentage reduction of PM in the case of Macadamia B5 blend was observed between the range from 5% to 22.5%, while the value of PM emission reduction for Macadamia B10 blend was between 17% and 34% compared to diesel. Grapeseed B5 blend and B10 blend reduced the PM emission by 5 to 25% and 15 to 41%, respectively compared to that of diesel. Grapeseed biodiesel blends produced lesser PM emission compared to that of Macadamia biodiesel blends. The higher reduction in PM emission for Grapeseed blends was most likely due to the lower carbon chain length in Grapeseed than Macadamia biodiesel. It could be noted the reduction of PM is statistically significant for Macadamia B5 vs. B10 blends (p-value = 0.004); Grapeseed B5 vs. B10 (p-value = 0.001), respectively. However, an insignificant reduction was found due to the p-value 0.607 and 0.100, which is higher than 0.05 when comparing between B5 and B10 Macadamia vs. Grapeseed blends, respectively.

3.2.5. Nitrogen Oxide (NO_x) Emission

The diesel engine emits a significant amount of NO_x during the combustion of fuel [70] and is highly dependent on the ratio of air-fuel mixture and in-cylinder temperature [71,72]. Figure 9 shows the increase in NO_x emission from the biodiesel blends compared to diesel at engine speeds from 1200 rpm to 2400 rpm. In general, the biodiesel blends showed higher NO_x emission compared to diesel due to the presence of a higher percentage of oxygen in biodiesel than the diesel [57]. Higher cetane number and oxygen content in biodiesel improves the combustion process and increases in-cylinder temperature, leading to an increase in NO_x emission [73,74]. However, compared to Grapeseed biodiesel blends, Macadamia biodiesel blends exhibited much higher NO_x emission. In the case of Macadamia biodiesel blends B5 and B10, the NO_x emission was increased by 24 to 28% and 21 to 24% and for Grapeseed blends B5 and B10 it was 0.1 to 4% and 2 to 10%, respectively. It can also be seen from the figure that biodiesel blend B10 resulted in higher NO_x emission compared to B5 for both Macadamia and Grapeseed biodiesel due to the presence of a higher oxygen content in the B10 blend. For both Macadamia and Grapeseed biodiesel blends, NO_x emission was reduced with the increase in engine speed as shown in Figure 9. The *t*-test indicates the increase of NO_x emissions is statistically significant as indicated by a *p*-value lower than 0.05 for all the cases compared to diesel.

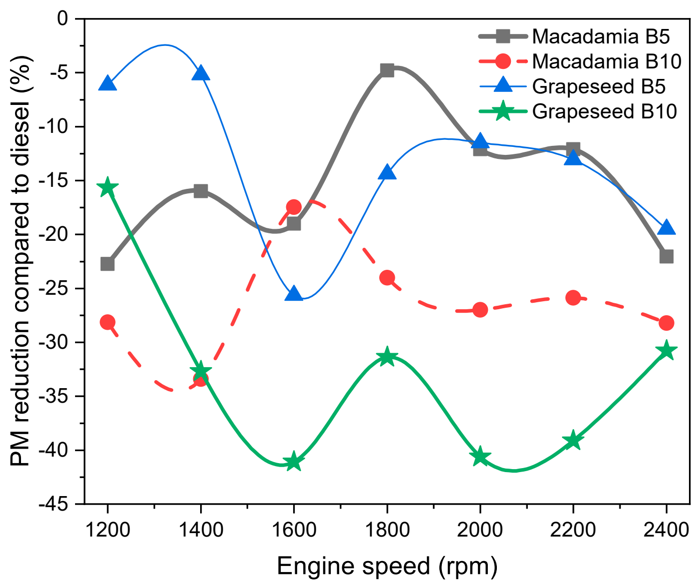

Figure 8. Particulate matters (PM) emission reduction compared to diesel using B5 and B10 biodiesel blends.

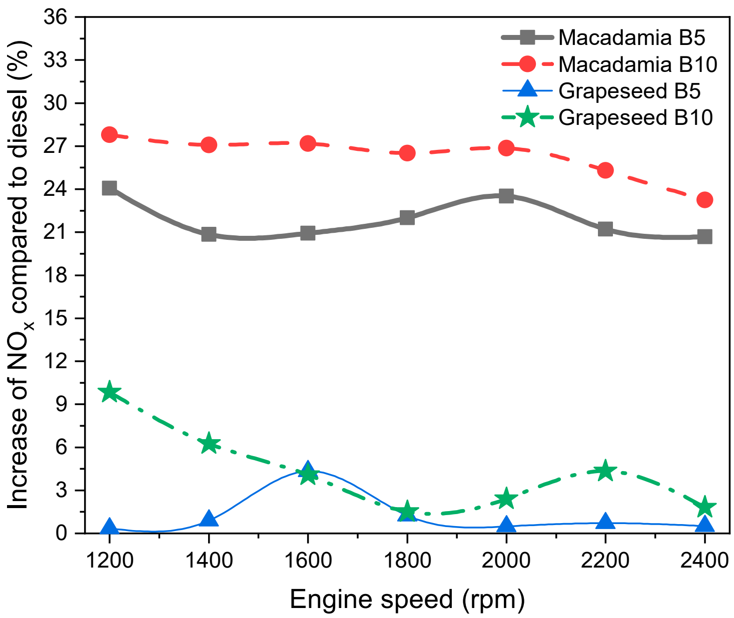

Figure 9. Effect on nitrogen oxide (NOx) emission compared to diesel using B5 and B10 biodiesel blends.

3.3. Combustion Analysis

3.3.1. Cylinder Pressure (CP)

Figure 10 represents the cylinder pressure at full engine load conditions for diesel and biodiesel blends used in this study. At 360° crank angle, diesel has the peak cylinder pressure of 67 bar. No noticeable difference in-cylinder pressure was observed between the diesel and Grapeseed biodiesel blends, though the Grapeseed biodiesel has higher kinematic viscosity than the diesel. The higher cylinder pressure for Grapeseed was also measured approximately 65 bar at a 360° crank angle. A similar effect of biodiesel on cylinder pressure was observed by Ghazali et al. [57] who stated that there was no distinct variation in peak cylinder pressure with biodiesel blends when compared to diesel [75,76]. However, Macadamia biodiesel blends B10 and B5 resulted in a slight increase in the in-cylinder pressure at 355 to 375° crank angle. The increase in-cylinder pressure for Macadamia biodiesel blends may be due to the higher cetane number of Macadamia biodiesel, which reduces the ignition delay [57,77].

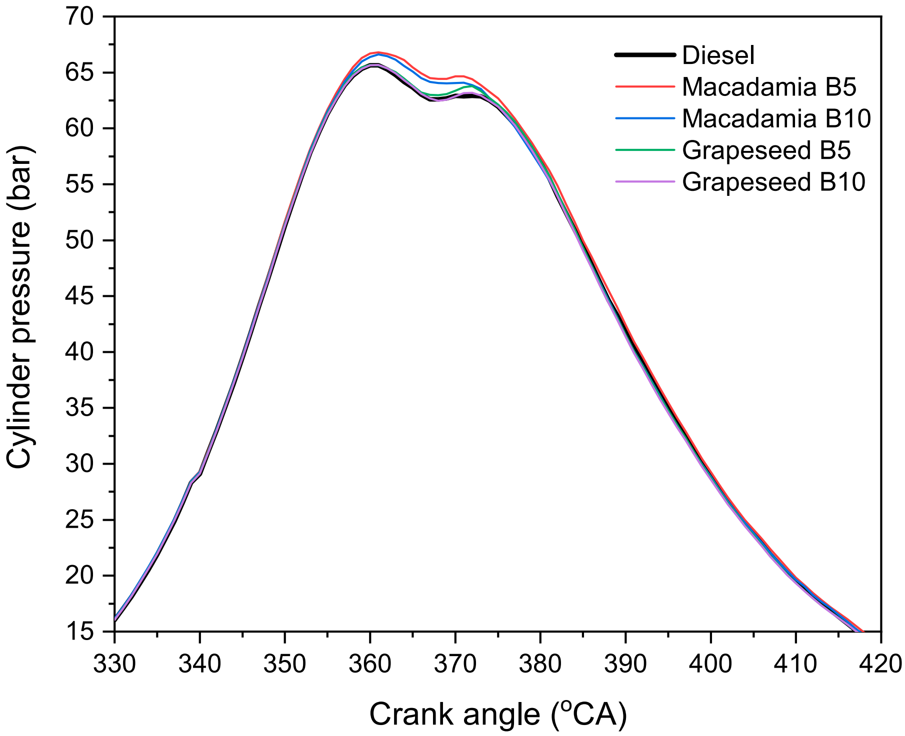

Figure 10. Variation of cylinder pressure with the crank angle at full engine load condition.

3.3.2. Heat Release Rate (HRR)

The heat release rate (HRR) of diesel, Macadamia B5, Macadamia B10, Grapeseed B5, and Grapeseed B10 biodiesel blends are presented in Figure 11. The experimental results suggested that the ignition occurred before the 360° crank angle; however, the peak heat release rate was noted only after a 370° crank angle. Azad and Rasul [61] stated that this time lag is required to attain the peak combustion after the ignition of the fuel. Although there was a variation in the physicochemical properties, for instance, kinematic viscosity, cetane number, the calorific value between diesel and biodiesel blends; the heat release rate of biodiesel blends was almost the same as that of diesel, as shown in Figure 11. Ghazali et al. [57] investigated the heat release rate of diesel, biodiesel blends and neat biodiesel and reported almost the same heat release rate for all the fuels. In addition, Karthickeyan [78] investigated the effect of piston geometry on engine combustion, performance and emission using Pumpkin seed oil and Moringa oleifera and found closer HRR with higher BTE and lower NO_x emission compared to other blends.

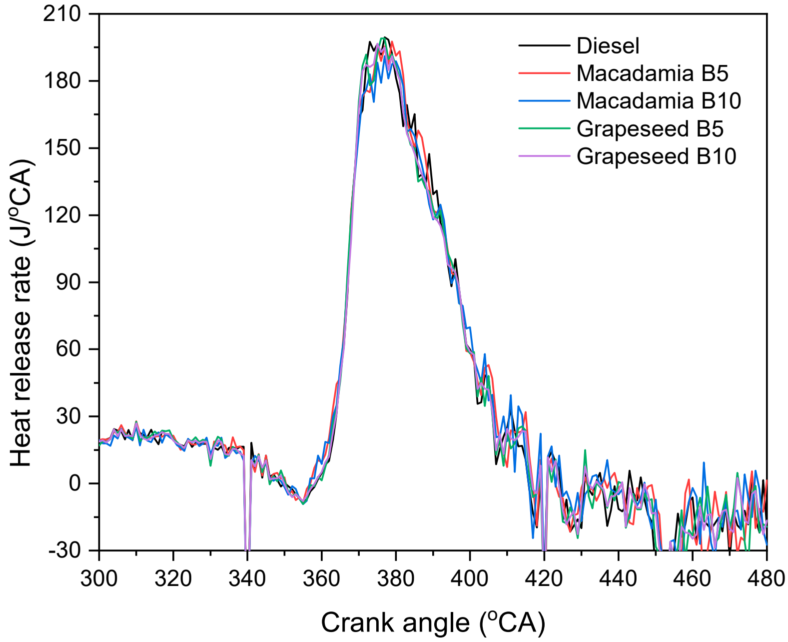

Figure 11. Variation of heat release rate with the crank angle at full engine load condition.

4. Conclusions and Recommendations

In the current study, the feasibility of using Macadamia and Grapeseed biodiesel in diesel engines was investigated under different engine speeds ranging between 1200 rpm and 2400 rpm. According to the experimental results and discussions, the following specific conclusions can be drawn.

- The experimental results suggest a higher BSFC for biodiesel blends compared to that of diesel. BSFC increased by 2 to 8.5% for B5 biodiesel blend and 3 to 16% for B10 biodiesel blend. On the contrary, BP and BTE were reduced in the case of biodiesel blends when compared with diesel fuel. The reduction in BP and BTE for B5 biodiesel blend was in the range of 0.5 to 6.5% and 2 to 7%, respectively, and for B10 biodiesel blend it was 0 to 8% and 2 to 12.5%, respectively. The higher BSFC and lower BP and BTE in the case of biodiesel blends were due to the lower calorific value of biodiesel than diesel fuel.
- The use of biodiesel blends in a diesel engine exhibited better emissions profile compared to diesel, particularly in the case of CO, the ratio of CO_2/CO, HC and PM emissions. It was observed that CO, CO_2/CO ratio, HC and PM emissions were significantly reduced when B5 and B10 biodiesel blends of Macadamia and Grapeseed biodiesel were used in the diesel engine instead of diesel only. The findings were also verified by conducting the *t*-test analysis. However, the increase in NO_x emission was observed for all biodiesel blends.
- The variation in-cylinder pressure and heat release rate with the crank angle for all the biodiesel blends was nearly the same as that of diesel fuel. Only a slight increase in-cylinder pressure was observed for Macadamia biodiesel blends B10 and B5 at a crank angle from 355 °CA to 375 °CA.

Although the biodiesel blends investigated in this study showed mixed engine responses in comparison to diesel, Macadamia and Grapeseed biodiesel can be a feasible alternative to diesel for the compression engine. Cleaner combustion of Macadamia and Grapeseed biodiesel due to the higher oxygen content in biodiesel can help in reducing environmental pollution. The study recommends further analysis on the tribological behaviour of the biodiesel blends and a comprehensive life-cycle economic analysis before recommending it for commercial application.

Author Contributions: Conceptualization, A.K.A.; methodology, A.K.A. and P.H.; software, P.H. and K.V.; formal analysis, J.A. and A.K.A.; investigation, M.G.R., M.M.K.K. and N.M.S.H.; resources, S.R.N.; data curation, A.K.A.; writing—original draft preparation, A.K.A., J.A., P.H., N.M.S.H. and S.R.N.; writing—review and editing, A.K.A., M.G.R., M.M.K.K. and K.V.; visualization, A.K.A, J.A.; supervision, M.G.R. and M.M.K.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Azad, A.; Rasul, M.; Khan, M.; Omri, A.; Bhuiya, M.; Ali, M. Modelling of renewable energy economy in Australia. *Energy Proc.* **2014**, *61*, 1902–1906. [CrossRef]
2. Hassan, N.M.; Rasul, M.; Harch, C. Modelling and experimental investigation of engine performance and emissions fuelled with biodiesel produced from Australian Beauty Leaf Tree. *Fuel* **2015**, *150*, 625–635. [CrossRef]
3. Lin, B.-J.; Chen, W.-H.; Hsieh, T.-H.; Ong, H.C.; Show, P.L.; Naqvi, S.R. Oxidative reaction interaction and synergistic index of emulsified pyrolysis bio-oil/diesel fuels. *Renew. Energy* **2019**, *136*, 223–234. [CrossRef]
4. Demirbas, A. Progress and recent trends in biodiesel fuels. *Energy Convers. Manag.* **2009**, *50*, 14–34. [CrossRef]
5. Tahir, M.H.; Zhao, Z.; Ren, J.; Rasool, T.; Naqvi, S.R. Thermo-kinetics and gaseous product analysis of banana peel pyrolysis for its bioenergy potential. *Biomass Bioenergy* **2019**, *122*, 193–201. [CrossRef]
6. Reza Miri, S.M.; Mousavi Seyedi, S.R.; Ghobadian, B. Effects of biodiesel fuel synthesized from non-edible rapeseed oil on performance and emission variables of diesel engines. *J. Clean. Prod.* **2017**, *142*, 3798–3808. [CrossRef]
7. Halder, P.; Azad, K.; Shah, S.; Sarker, E. Prospects and technological advancement of cellulosic bioethanol ecofuel production. In *Advances in Eco-Fuels for a Sustainable Environment*; Azad, K., Ed.; Woodhead Publishing: Cambridge, UK, 2019; pp. 211–236.
8. Naqvi, S.R.; Naqvi, M.; Noor, T.; Hussain, A.; Iqbal, N.; Uemura, Y.; Nishiyama, N. Catalytic Pyrolysis of *Botryococcus Braunii* (microalgae) Over Layered and Delaminated Zeolites for Aromatic Hydrocarbon Production. *Energy Proc.* **2017**, *142*, 381–385. [CrossRef]
9. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Mofijur, M.; Bhuiya, M.M.K. Prospects, feedstocks and challenges of biodiesel production from beauty leaf oil and castor oil: A nonedible oil sources in Australia. *Renew. Sustain. Energy Rev.* **2016**, *61*, 302–318. [CrossRef]
10. Bhuiya, M.; Rasul, M.; Khan, M.; Ashwath, N.; Azad, A.; Mofijur, M. Optimisation of oil extraction process from Australian native beauty leaf seed (*Calophyllum inophyllum*). *Energy Proc.* **2015**, *75*, 56–61. [CrossRef]
11. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Islam, R. Prospect of Moringa seed oil as a sustainable biodiesel fuel in Australia: A review. *Proc. Eng.* **2015**, *105*, 601–606. [CrossRef]
12. Halder, P.; Azad, A.K. Chapter 7—Recent trends and challenges of algal biofuel conversion technologies. In *Advanced Biofuels*; Azad, A.K., Rasul, M., Eds.; Woodhead Publishing: Cambridge, UK, 2019; pp. 167–179.
13. Ashok, B.; Nanthagopal, K.; Saravanan, B.; Azad, K.; Patel, D.; Sudarshan, B.; Aaditya Ramasamy, R. Study on isobutanol and *Calophyllum inophyllum* biodiesel as a partial replacement in CI engine applications. *Fuel* **2019**, *235*, 984–994. [CrossRef]
14. Rahman, M.M.; Rasul, M.G.; Hassan, N.M.S.; Azad, A.K.; Uddin, M.N. Research, Effect of small proportion of butanol additive on the performance, emission, and combustion of Australian native first-and second-generation biodiesel in a diesel engine. *Environ. Sci. Pollut. Res.* **2017**, *24*, 22402–22413. [CrossRef] [PubMed]
15. Sanjid, A.; Masjuki, H.H.; Kalam, M.A.; Rahman, S.M.A.; Abedin, M.J.; Palash, S.M. Production of palm and jatropha based biodiesel and investigation of palm-jatropha combined blend properties, performance, exhaust emission and noise in an unmodified diesel engine. *J. Clean. Prod.* **2014**, *65*, 295–303. [CrossRef]
16. Chhetri, A.; Tango, M.; Budge, S.; Watts, K.; Islam, M.J.I.J.o.M.S. Non-edible plant oils as new sources for biodiesel production. *Int. J. Mol. Sci.* **2008**, *9*, 169–180. [CrossRef]
17. Knothe, G.; Razon, L.F. Biodiesel fuels. *Progress Energy Combust. Sci.* **2017**, *58*, 36–59. [CrossRef]
18. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Hazrat, M.A. Prospect of biofuels as an alternative transport fuel in Australia. *Renew. Sustain. Energy Rev.* **2015**, *43*, 331–351. [CrossRef]

19. Azad, K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C. Introduction to sustainable and alternative ecofuels. In *Advances in Eco-Fuels for a Sustainable Environment*; Azad, K., Ed.; Woodhead Publishing: Cambridge, UK, 2019; pp. 1–14.
20. Azad, A.K.; Rasul, M.G.; Bhuiya, M.G.; Islam, R. Effect of first and second generation biodiesel blends on engine performance and emission. *AIP Conf. Proc.* **2016**, *1754*, 050031.
21. Abhilash, P.; Srivastava, P.; Jamil, S.; Singh, N. Revisited Jatropha curcas as an oil plant of multiple benefits: Critical research needs and prospects for the future. *Environ. Sci. Pollut. Res.* **2011**, *18*, 127–131. [CrossRef]
22. Atabani, A.; Silitonga, A.; Ong, H.; Mahlia, T.; Masjuki, H.; Badruddin, I.A.; Fayaz, H.J.R. Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renew. Sustain. Energy Rev.* **2013**, *18*, 211–245. [CrossRef]
23. Kumar, A.; Patil, N.; Kumar, R.; Mandal, D. Irrigation scheduling and fertilization improves production potential of Jatropha (*Jatropha curcas* L.). A review. *Int. J. Curr. Microbiol. App. Sci.* **2016**, *6*, 1703–1716. [CrossRef]
24. Ashok, B.; Saravanan, B.; Nanthagopal, K.; Azad, A.K. Chapter 11—Investigation on the effect of butanol isomers with gasoline on spark ignition engine characteristics. In *Advanced Biofuels*; Azad, A.K., Rasul, M., Eds.; Woodhead Publishing: Cambridge, UK, 2019; pp. 265–289.
25. Ali, O.M.; Mamat, R.; Abdullah, N.R.; Abdullah, A.A. Analysis of blended fuel properties and engine performance with palm biodiesel–diesel blended fuel. *Renew. Energy* **2016**, *86*, 59–67. [CrossRef]
26. Nisar, J.; Razaq, R.; Farooq, M.; Iqbal, M.; Khan, R.A.; Sayed, M.; Shah, A.; Rahman, I. Enhanced biodiesel production from Jatropha oil using calcined waste animal bones as catalyst. *Renew. Energy* **2017**, *101*, 111–119. [CrossRef]
27. Eloka-Eboka, A.C.; Inambao, F.L. Hybridization of feedstocks—A new approach in biodiesel development: A case of Moringa and Jatropha seed oils. *Energy Sources Part A Recovery Util. Environ. Effects* **2016**, *38*, 1495–1502. [CrossRef]
28. Agarwal, A.K. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress Energy Combust. Sci.* **2007**, *33*, 233–271. [CrossRef]
29. Sahoo, P.; Das, L.; Babu, M.; Arora, P.; Singh, V.; Kumar, N.; Varyani, T. Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine. *Fuel* **2009**, *88*, 1698–1707. [CrossRef]
30. Sahoo, P.; Das, L. Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. *Fuel* **2009**, *88*, 994–999. [CrossRef]
31. Dhar, A.; Kevin, R.; Agarwal, A.K. Production of biodiesel from high-FFA neem oil and its performance, emission and combustion characterization in a single cylinder DICI engine. *Fuel Proces. Technol.* **2012**, *97*, 118–129. [CrossRef]
32. Nalgundwar, A.; Paul, B.; Sharma, S.K. Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha. *Fuel* **2016**, *173*, 172–179. [CrossRef]
33. Patel, S.; Azad, A.K.; Khan, M. Numerical investigation for predicting diesel engine performance and emission using different fuels. *Energy Proc.* **2019**, *160*, 834–841. [CrossRef]
34. Atadashi, I.M.; Aroua, M.K.; Abdul Aziz, A.R.; Sulaiman, N.M.N. Production of biodiesel using high free fatty acid feedstocks. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3275–3285. [CrossRef]
35. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Bhuiya, M.M.K.; Mofijur, M. A review on socio-economic aspects of sustainable biofuels. *Int. J. Glob. Warm.* **2016**, *10*, 32–54. [CrossRef]
36. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Bhuiya, M.M.K. Study on Australian energy policy, socio-economic, and environment issues. *J. Renew. Sustain. Energy* **2015**, *7*, 063131. [CrossRef]
37. Venkatesan, H.; Sivamani, S. Evaluating the predicting capability of response surface methodology on biodiesel production from grapeseed bio-oil. *Energy Sources Part A Recovery Util. Environ. Effects* **2019**, 1–16. [CrossRef]
38. Chelladorai, P.; Varuvel, E.G.; Martin, L.J.; Bedhannan, N. Synergistic effect of hydrogen induction with biofuel obtained from winery waste (grapeseed oil) for CI engine application. *Int. J. Hydrogen Energy* **2018**, *43*, 12473–12490. [CrossRef]
39. Vedagiri, P.; Martin, L.J.; Varuvel, E.G. Characterization study on performance, combustion and emission of nano additive blends of grapeseed oil methyl ester fuelled CI engine with various piston bowl geometries. *Heat Mass Transf.* **2020**, *56*, 715–726. [CrossRef]

40. Vedagiri, P.; Martin, L.J.; Varuvel, E.G.; Subramanian, T. Experimental study on NOx reduction in a grapeseed oil biodiesel-fueled CI engine using nanoemulsions and SCR retrofitment. *Environ. Sci. Pollut. Res.* **2019**, 1–14. [CrossRef]
41. Praveena, V.; Leenus Jesu Martin, M.; Edwin Geo, V. Effect of EGR on emissions of a modified DI compression ignition engine energized with nanoemulsive blends of grapeseed biodiesel. *Fuel* **2020**, *267*, 117317. [CrossRef]
42. Bhuiya, M.M.K.; Rasul, M.G.; Khan, M.M.K.; Ashwath, N.; Azad, A.K. Prospects of 2nd generation biodiesel as a sustainable fuel—Part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1109–1128. [CrossRef]
43. Barnwal, B.K.; Sharma, M.P. Prospects of biodiesel production from vegetable oils in India. *Renew. Sustain. Energy Rev.* **2005**, *9*, 363–378. [CrossRef]
44. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C. Biodiesel from Queensland Bush Nut (*Macadamia integrifolia*). In *Clean Energy for Sustainable Development*; Rasul, M.G., Azad, A.k., Sharma, S.C., Eds.; Academic Press: Cambridge, MA, USA, 2017; pp. 419–439.
45. Knothe, G.J.E. Biodiesel derived from a model oil enriched in palmitoleic acid, macadamia nut oil. *Energy Fuels* **2010**, *24*, 2098–2103. [CrossRef]
46. Nabi, M.N.; Rasul, M.G. Influence of second generation biodiesel on engine performance, emissions, energy and exergy parameters. *Energy Conv. Manag.* **2018**, *169*, 326–333. [CrossRef]
47. Azad, A. Biodiesel from mandarin seed oil: A surprising source of alternative fuel. *Energies* **2017**, *10*, 1689. [CrossRef]
48. Azad, A.K.; Rasul, M.G.; Bhatt, C. Combustion and emission analysis of Jojoba biodiesel to assess its suitability as an alternative to diesel fuel. *Energy Proc.* **2019**, *156*, 159–165. [CrossRef]
49. Karthickeyana, V.; Thiyagarajan, S.; Ashok, B.; Edwin Geo, V.; Azad, A.K. Experimental investigation of pomegranate oil methyl ester in ceramic coated engine at different operating condition in direct injection diesel engine with energy and exergy analysis. *Energy Conv. Manag.* **2020**, *205*, 112334. [CrossRef]
50. Azad, K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C. 12—Ecofuel and its compatibility with different automotive metals to assess diesel engine durability. In *Advances in Eco-Fuels for a Sustainable Environment*; Azad, K., Ed.; Woodhead Publishing: Cambridge, UK, 2019; pp. 337–351.
51. Azad, A.K.; Rasul, M.G.; Sharma, S.C.; Khan, M.M.K.J.E. The Lubricity of Ternary Fuel Mixture Blends as a Way to Assess Diesel Engine Durability. *Energies* **2018**, *11*, 33. [CrossRef]
52. Ong, H.C.; Mofijur, M.; Silitonga, A.; Gumilang, D.; Kusumo, F.; Mahlia, T. Physicochemical Properties of Biodiesel Synthesised from Grape Seed, Philippine Tung, Kesambi, and Palm Oils. *Energies* **2020**, *13*, 1319. [CrossRef]
53. Jeyalakshmi, P. Characterization of Simarouba glauca seed oil biodiesel. *J. Therm. Anal. Calorim.* **2019**, *136*, 267–280. [CrossRef]
54. Fadhil, A.B. Evaluation of apricot (*Prunus armeniaca* L.) seed kernel as a potential feedstock for the production of liquid bio-fuels and activated carbons. *Energy Convers. Man.* **2017**, *133*, 307–317. [CrossRef]
55. Ong, H.C.; Masjuki, H.H.; Mahlia, T.M.I.; Silitonga, A.S.; Chong, W.T.; Yusaf, T. Engine performance and emissions using Jatropha curcas, Ceiba pentandra and *Calophyllum inophyllum* biodiesel in a CI diesel engine. *Energy* **2014**, *69*, 427–445. [CrossRef]
56. An, H.; Yang, W.M.; Maghbouli, A.; Li, J.; Chou, S.K.; Chua, K.J. Performance, combustion and emission characteristics of biodiesel derived from waste cooking oils. *Appl. Energy* **2013**, *112*, 493–499. [CrossRef]
57. Wan Ghazali, W.N.M.; Mamat, R.; Masjuki, H.H.; Najafi, G. Effects of biodiesel from different feedstocks on engine performance and emissions: A review. *Renew. Sustain. Energy Rev.* **2015**, *51*, 585–602. [CrossRef]
58. Azad, A.K.; Rasul, M.G.; Giannangelo, B.; Ahmed, S.F. Diesel Engine Performance and Emission Study Using Soybean Biodiesel Blends with Fossil Diesel. In *Exergy for A Better Environment and Improved Sustainability 2: Applications*; Aloui, F., Dincer, I., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 137–155.
59. Azad, A.K.; Rasul, M.; Khan, M.M.; Sharma, S.C. Macadamia Biodiesel as a Sustainable and Alternative Transport Fuel in Australia. *Energy Proc.* **2017**, *110*, 543–548. [CrossRef]
60. Knothe, G. A comprehensive evaluation of the cetane numbers of fatty acid methyl esters. *Fuel* **2014**, *119*, 6–13. [CrossRef]
61. Azad, K.; Rasul, M. Performance and combustion analysis of diesel engine fueled with grape seed and waste cooking biodiesel. *Energy Proc.* **2019**, *160*, 340–347. [CrossRef]

62. Uddin, S.M.A.; Azad, A.K.; Alam, M.M.; Ahamed, J.U. Performance of a diesel engine run with mustard-kerosene blends. *Proc. Eng.* **2015**, *105*, 698–704. [CrossRef]
63. Srivastava, P.K.; Verma, M. Methyl ester of karanja oil as an alternative renewable source energy. *Fuel* **2008**, *87*, 1673–1677. [CrossRef]
64. Yesilyurt, M.K.; Aydin, M. Experimental investigation on the performance, combustion and exhaust emission characteristics of a compression-ignition engine fueled with cottonseed oil biodiesel/diethyl ether/diesel fuel blends. *Energy Convers. Manag.* **2020**, *205*, 112355. [CrossRef]
65. Abed, K.A.; Gad, M.S.; El Morsi, A.K.; Sayed, M.M.; Elyazeed, S.A. Effect of biodiesel fuels on diesel engine emissions. *Egypt. J. Pet.* **2019**, *28*, 183–188. [CrossRef]
66. Zhihao, M.; Xiaoyu, Z.; Junfa, D.; Xin, W.; Bin, X.; Jian, W. Study on Emissions of a DI Diesel Engine Fuelled with Pistacia Chinensis Bunge Seed Biodiesel-Diesel Blends. *Proc. Environ. Sci.* **2011**, *11*, 1078–1083. [CrossRef]
67. Wang, S.; Viswanathan, K.; Esakkimuthu, S.; Azad, K. Experimental investigation of high alcohol low viscous renewable fuel in DI diesel engine. *Environ. Sci. Pollut. Res.* **2020**, 15. [CrossRef]
68. Rajak, U.; Nashine, P.; Verma, T.N. Effect of spirulina microalgae biodiesel enriched with diesel fuel on performance and emission characteristics of CI engine. *Fuel* **2020**, *268*, 117305. [CrossRef]
69. Bhuiya, M.M.K.; Rasul, M.G.; Khan, M.M.K.; Ashwath, N.; Azad, A.K.; Hazrat, M.A. Prospects of 2nd generation biodiesel as a sustainable fuel–Part 2: Properties, performance and emission characteristics. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1129–1146. [CrossRef]
70. Rashed, M.; Kalam, M.; Masjuki, H.; Habibullah, M.; Imdadul, H.; Shahin, M.; Rahman, M.J.I.c. Improving oxidation stability and NOX reduction of biodiesel blends using aromatic and synthetic antioxidant in a light duty diesel engine. *Ind. Crops Prod.* **2016**, *89*, 273–284. [CrossRef]
71. Li, L.; Wang, J.; Wang, Z.; Xiao, J. Combustion and emission characteristics of diesel engine fueled with diesel/biodiesel/pentanol fuel blends. *Fuel* **2015**, *156*, 211–218. [CrossRef]
72. Karthickeyan, V.; Thiyagarajan, S.; Geo, V.E.; Ashok, B.; Nanthagopal, K.; Chyuan, O.H.; Vignesh, R. Simultaneous reduction of NOx and smoke emissions with low viscous biofuel in low heat rejection engine using selective catalytic reduction technique. *Fuel* **2019**, *255*, 115854. [CrossRef]
73. Gürü, M.; Koca, A.; Can, Ö.; Çınar, C.; Şahin, F. Biodiesel production from waste chicken fat based sources and evaluation with Mg based additive in a diesel engine. *Renew. Energy* **2010**, *35*, 637–643. [CrossRef]
74. Rakopoulos, C.D.; Antonopoulos, K.A.; Rakopoulos, D.C. Multi-zone modeling of Diesel engine fuel spray development with vegetable oil, bio-diesel or Diesel fuels. *Energy Convers. Manag.* **2006**, *47*, 1550–1573. [CrossRef]
75. Azad, A.K.; Halder, P.; Nanthagopal, K.; Ashok, B. Chapter 13—Investigation of diesel engine in cylinder flow phenomena using CFD cold flow simulation. In *Advanced Biofuels*; Azad, A.K., Rasul, M., Eds.; Woodhead Publishing: Cambridge, UK, 2019; pp. 329–336.
76. Karthickeyan, V.; Ashok, B.; Nanthagopal, K.; Thiyagarajan, S.; Geo, V.E. Investigation of novel Pistacia khinjuk biodiesel in DI diesel engine with post combustion capture system. *Appl. Therm. Eng.* **2019**, *159*, 113969. [CrossRef]
77. Azad, A.K.; Rasul, M.G.; Khan, M.M.K.; Sharma, S.C.; Bhuiya, M.M.K. Recent development of biodiesel combustion strategies and modelling for compression ignition engines. *Renew. Sustain. Energy Rev.* **2016**, *56*, 1068–1086. [CrossRef]
78. Karthickeyan, V. Effect of combustion chamber bowl geometry modification on engine performance, combustion and emission characteristics of biodiesel fuelled diesel engine with its energy and exergy analysis. *Energy* **2019**, *176*, 830–852. [CrossRef]