Article

Testing of JTD Engine Fueled with Hemp and Rapeseed Oil Esters

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Abstract

Alternative fuels to fossil fuels have been a focus of research since the 1980s, due to the oil crisis. Biofuels for diesel engines are obtained from various types of fats, primarily vegetable oils. Soybean and rapeseed oil are mainly used to produce biofuels. The aim of the research undertaken was to compare the performance characteristics of a 1.3 JTD engine fueled with methyl esters from hemp compared to biofuels made from rapeseed and fossil fuels. Energy parameters and exhaust emissions were measured. The fuels used were 100% biofuels obtained from vegetable oils by transesterification using methanol and KOH. It was shown to be possible to use HME (hemp methyl esters) biofuels as an alternative fuel to RME (rapeseed methyl esters) or DF (diesel fuel) without significant changes in engine performance. The density and heat of combustion of such fuels results in a 6% reduction in power and 17% in NO_x emissions, as well as a decrease in HC (hydrocarbons), CO_2, and smoke emissions.

Keywords: engine performance; RME; hemp oil; biodiesel; combustion process

1. Introduction

Hemp (*Cannabis sativa* L.) is an herbaceous plant used in the medicine, food, and textile industries [1]. European Union regulations allow the cultivation of hemp varieties that are characterized by the content of δ-9-tetrahydrocannabinol (THC) below 0.2% [2]. The ban on cultivating, transforming, and commercializing specific hemp varieties containing <0.3% THC in the United States has been lifted [3]. The essential products from hemp processing are protein (used in food and feed production), fiber (used in the textile and paper industries), and oil [4]. Hemp seeds contain 25–35% lipids, 20–25% protein, 20–30% carbohydrates, and 10–15% insoluble fiber [4,5]. To obtain oil with higher taste values, hemp seeds are usually subjected to a low-temperature pressing process or supercritical

CO_2 extraction [6,7]. The cultivars planted and their growth condition directly impact the oil's composition. The oils contain linoleic acid (55.4–59.6%), α-linoleic acid (16.5–20.4%), oleic acid (11.4–15.9%), palmitic acid (6.1–6.8%), and stearic acid (2.3–2.7%) [8]. Hemp seed oil is a nutritious and versatile oil that comes from the seeds of the Cannabis sativa plant. Hemp oil has an optimal ratio of omega-3 to omega-6 fatty acids (3:1), which may help lower blood pressure and cholesterol levels and prevent cardiovascular diseases [9,10]. Hemp seed oil is a rich source of flavonoids, terpenes, carotenoids, and phytosterols. Due to its anti-inflammatory and anti-aging properties, this oil can also be used in cosmetics.

Due to the high emissions from burning fossil fuels, ways to control this problem are being sought [11]. In the 1990s, work began on finding alternative fuels for diesel engines, like vegetable oil [12]. Experimental results indicated the need to modify either the vegetable oils or the internal combustion engine. One such engine modification involves a John Deere agricultural tractor, which was adapted to canola oil from the factory [13]. Another solution is multi-fuel installations and the use of blends of vegetable oil with conventional fuel [14]. It has been recognized that modifying fat by esterifying may yield the best solution [15]. There is also much criticism of biofuels competing with food production [16] and waste feedstocks, such as UCO (used cooking oil), are being sought to produce biofuels [17,18]. Another potential solution is oil from microalgae, which has unlimited production potential [19]. Lodi et al. demonstrated the effect of algae biofuel addition on diesel engine performance [20]. Another source of biofuel feedstock is Jatropha oil. Mehra et al. reported a 10% increase in engine thermal efficiency using a blend of biodiesel including Jatropha oil and diesel [21]. Venkatesan et al. confirmed an 18% increase in NO_x emissions and 20% and 12% reductions in CO and HC, respectively, using a 50% addition of biodiesel with Jatropha oil [22]. Rajpoot et al. proved that regardless of the type of feedstock (palm oil, jatropha oil, or microalgae oil), there is an increase in NO_x emissions and specific fuel consumption [23]. The use of biofuels, in addition to fossil fuels, increases NO_x emissions while significantly reducing HC, CO, and PM (particulate matter) emissions [24,25]. Yildiz et al. found that the high density and viscosity of biofuels are the reason for engine performance deterioration [26]. This problem was solved by Viswnanthan et al. using biofuels with petitgrain bitter orange oil at extreme engine operating parameters [27]. Kabudke et al. studied the effect of adding biofuel with cottonseed oil and recorded a significant reduction in BSFC-specific fuel consumption [28]. Asokan et al. described the use of hemp oil in the transesterification reaction with methanol in the presence of potassium hydroxide, which resulted in biodiesel [29]. Research has shown that the combustion of a mixture containing 20% biodiesel and 80% diesel reduced CO, HC, and NO_x emissions compared to the combustion of pure diesel. Methyl esters derived from rapeseed oil and hemp oil differ primarily in their fatty acid compositions, which significantly affect their suitability as biofuels [30,31]. Rapeseed oil methyl esters are characterized by a higher content of monounsaturated fatty acids, resulting in greater oxidative stability and a higher cetane number, both of which translate into superior ignition properties in diesel engines [32]. In contrast, hemp oil methyl esters possess a higher proportion of polyunsaturated fatty acids, which leads to lower oxidative stability but provides a lower pour point, making them advantageous under cold climate conditions [33]. The increased oxidative stability of rapeseed oil methyl esters enhances their resistance to degradation and contributes to better engine protection, whereas hemp oil methyl esters may be more susceptible to oxidation during storage. Consequently, rapeseed oil methyl esters are considered more versatile as a biofuel, while hemp oil methyl esters may be particularly suitable for applications requiring improved low-temperature performance [34,35].

The research around the world is focused on biofuel production from various feedstocks and their effects on diesel engine performance [36]. The undertaking of this study stems from a significant informational gap regarding the performance characteristics of an engine fueled entirely with hemp oil methyl esters (HME), as compared to conventional rapeseed biodiesel and diesel fuel. Previous research has primarily focused on analyzing HME blends with diesel in the range of 10–75% [29,37,38], as well as the effects of adding up to 20% bioethanol [39]. However, comprehensive data on the complete substitution of conventional fuels with 100% HME are lacking, which limits the assessment of its potential as an alternative energy source in transportation.

The results of the experimental research and comparative analysis presented in this study constitute a valuable contribution to the development of hemp-based biofuels, providing new insights into their operational properties and energy efficiency. In the context of dynamic economic changes and the growing demand for sustainable energy sources [40–42], the findings may have practical applications, supporting decision-making processes related to the implementation of innovative fuel solutions in the transport sector.

2. Research Methodology

2.1. Scope of Experimental Research

The objective of this research was to evaluate the full-load performance characteristics of a compression ignition engine fueled with three fuels: 100% conventional diesel fuel (DF), 100% rapeseed methyl esters (RME), and 100% hemp oil methyl esters (HME). Prior to engine operation, both biofuels were synthesized and subjected to compositional analysis using a Hewlett Packard 6890 gas chromatograph (Agilent Technologies Inc., Santa Clara, CA, USA) in accordance with applicable fuel testing protocols. All experiments were performed on an engine test bench equipped with a Fiat 1.3 JTD common rail diesel engine. External characteristics were tested at full engine load for each rotational speed. During the tests, the parameters of the engine when running on standard and modified fuels were compared. Exhaust emissions were measured according to the standard ISO 8178–1 [43]. No modifications were made to the engine, which operated using the factory settings. Compression ignition engines are controlled by a controller that manages their operation and automatically adjusts the operating parameters to external conditions.

Full-load characteristics were determined under steady-state conditions across the entire engine speed range, with measurements taken at wide-open throttle for each fuel. To ensure measurement consistency and eliminate residual effects, the engine's fuel system was thoroughly purged before switching to a different fuel.

2.2. Fuel Parameters and Production Methodology

Methyl esters were obtained from cold-pressed unrefined oil. The seeds were pressed at 40–50 °C. The vegetable oil was filtered through a plate filter and trans esterified using 90% KOH dissolved in methanol of 99.8% purity. The process temperature was 60 °C and stirring took place for 60 min. Separation of the glycerol phase from the ester phase occurred after 24 h of sedimentation. The ester phase was washed with deionized water to a neutral pH = 7.0, then dried with anhydrous sodium sulfate and filtered. The diesel fuel and methyl esters are shown in Figure 1.

Analysis of the fatty acid profile, the data needed to calculate the physical parameters, was performed using GC-MS (gas chromatography–mass spectrometry). The detailed measurement method is described in the work of Golimowski et al. and Woloszyn et al. [30,44].
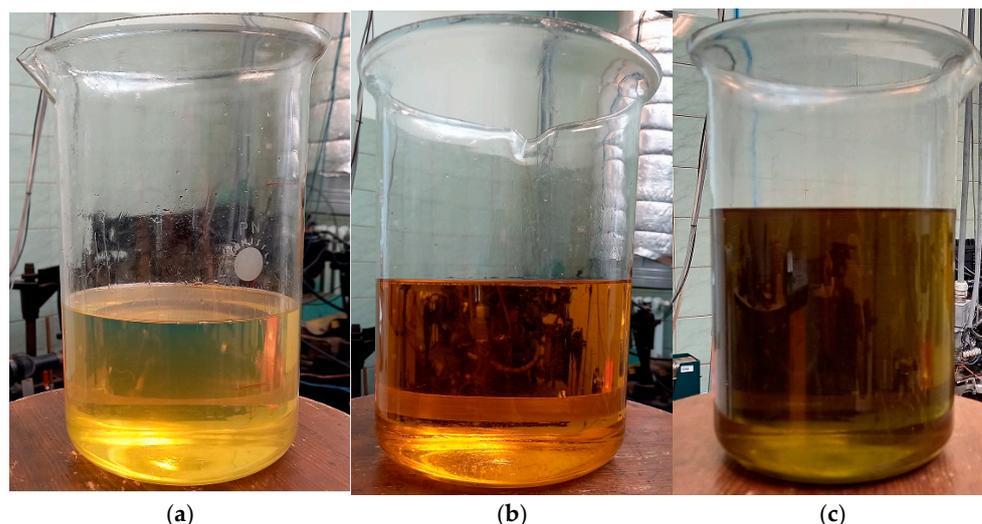
Figure 1. Fuel used in study: (**a**) diesel fuel; (**b**) rapeseed methyl ester; (**c**) hemp methyl ester.

BiodieselAnalyzer© software (version 2.2, BRTeam, Karaj, Iran) was used to deter-mine the physical parameters of the biofuel samples. The method was described in the works of Ramírez-Verduzco et al. [45] and Islam et al. [46]. The use of this program, dedicated to the evaluation of biofuels, allows quick and cost-free assessment of many parameters. It has already been used by our team in research on biofuels from microalgae [47]. Multi-criteria evaluation of biofuel quality requires the use of several mathematical models. The PROMETHEE method, operating with the help of mathematical models, is a tool for estimating multi-criteria evaluation of biofuel quality. In accordance with references [46,48], seven parameters were selected, for which the highest weight was assigned to the heating value (HHV = 0.5), followed by the cetane number (CN = 0.2). The weighting coefficients for the other parameters were the same at 0.06 (Table 1).

Table 1. Parameters of fuel used in study.

Parameters	Unit	RME	HME	DF EN590 [49]
Saturated fatty acid	(SFA)	7.26	11.81	-
Monosaturated fatty acid	(MUFA)	69.93	86.98	-
Polyunsaturated fatty acids	(PUFA)	22.61	0.00	-
Degree of unsaturation	(DU)	115.15	86.98	-
Saponification value	(SV)	198.78	196.56	-
Iodine value	(IV)	109.21	78.18	-
Cetan number	(CN)	49.19	56.48	51
Long-chain saturated factor	(LCSF)	2.39	4.85	-
Cold filter plugging point	(CFPP; °C)	−9.00	−1.00	−10
Cloud point	(CP; °C)	−3.00	−1.00	-
Allylic position equivalents	(APE)	113.69	86.37	-
Bis-allylic position equivalents	(BAPE)	29.83	2.52	-
Oxidation stability	(OS; h)	7.81	4.09	-
Higher heating value	(HHV; MJ·kg^{-1})	39.48	39.15	42.00
Kinematic viscosity 40 °C	(mm^2·s^{-1})	1.35	1.40	2.00
Density 15 °C	(g·cm^{-3})	0.87	0.85	0.82

2.3. Description of the Test Procedure

The Automex AMX 100 electric brake (ODIUT Automex Sp z o. o., Gdańsk, Poland) with a control system is a device used to collect and measure the power of combustion engines placed on a test bench (Figure 2). The brake's power absorption is 100 kW, its maximum rotational speed is 10,000 rpm, and its maximum torque is 240 Nm. The brake is

equipped with a cooling system, a fuel consumption measurement system in the form of an Automex ATMX 212F fuel mass meter (ODIUT Automex Sp z o. o., Gdańsk, Poland), and a dynamometer control system. The measurement accuracy of the entire test bench is 2%.
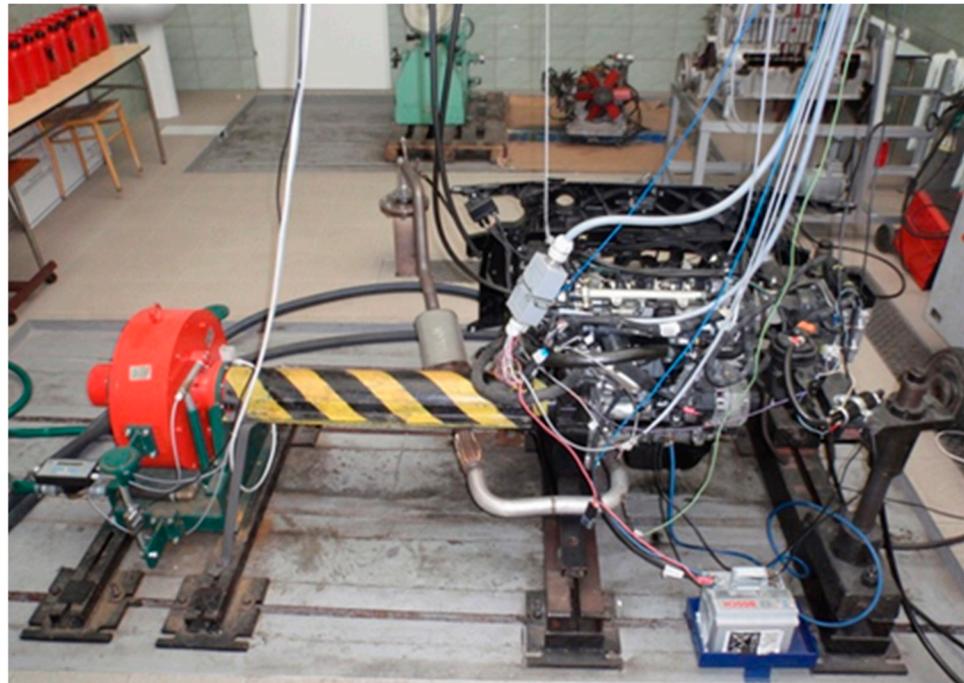

Figure 2. Engine test stand.

The gaseous composition of the exhaust gas was measured with a Capelec CAP 3201 analyzer (Capelec SAS, Montpellier, France), using the non-dispersive infrared spectroscopy (NDIR) method. The device can determine the concentration of basic gaseous components, such as CO, CO_2, HC, and O_2, with class 0 accuracy according to OIML R99 [50], ISO 3930 [51], BAR 97 [52], and MID standards [53]. For each gas, a unique wavelength range in the infrared spectrum is selected to measure the point where strong absorption occurs and where no other gases are absorbents. The gas flows through a measuring chamber, at the ends of which there are three infrared detectors and three emitters. Optical filters transmitting only a given wavelength range are placed in front of the thermocouple detector. Once the system is filled with the gas to be analyzed, the infrared detector measures the energy loss in the infrared range obtained for the wavelength range corresponding to each gas. Table 2 describes the measurement parameters recorded using the device.

Table 2. Analyzer measurement characteristics recorded with CAP 3201.

Component of Exhaust Gases	Measurement Range	Resolution
CO	0–15%	0.001%
CO_2	0–20%	0.1%
HC	0–20,000 ppm	1 ppm
O_2	0–21.7%	0.01%
Lamda	0.8–1.2	0.001
NO_x	0–5000 ppm	1 ppm

For the measurement of nitrogen oxide (NO and NO_2) concentrations, the analyzer was equipped with an additional electrochemical sensor dedicated to NOx detection. Measurement of the concentration of particulate matter (opacity) in the exhaust gas of a

compression ignition engine was carried out using an MDO 2 LON opacimeter (MAHA Maschinenbau Haldenwang GmbH & Co. KG, Haldenwang, Germany), based on the principle of absorption photometry. The device makes it possible to determine the light absorption coefficient (the "k" value [1/m]) in accordance with the current regulations for evaluating diesel engine emissions. The smoke meter's measurement error is 5%.

To obtain the full load performance map of the engine, a series of steady-state measurements were carried out under wide-open throttle (WOT) conditions. The engine was operated at discrete speed setpoints across its entire operational range, with full fuel delivery maintained at each point. Torque was measured using an eddy current dynamometer, and the corresponding engine power was calculated according to ISO 1585 [54]. Fuel consumption was continuously monitored to determine the associated brake-specific fuel consumption (BSFC). All measurements were conducted after the engine reached thermal steady-state, with coolant and oil temperatures stabilized within manufacturer-recommended limits. The resulting data allowed for the determination of engine torque, power output, and efficiency as a function of engine speed under maximum load conditions. JTD engines parameters have been described in Table 3.

Table 3. Test 1.3 JTD engine parameters.

Parameters	Unit	Value
Piston diameter	[mm]	69.6
Stroke	[mm]	82
Displacement	[cm^3]	1248
Power	[kW]	51
Revolution in max. power	[rpm]	4000
Max. torque	[Nm]	145
Revolution in max. torque	[rpm]	1750
Compression ratio	[-]	18.1

3. Experimental Results

3.1. Performance of the Engine

An analysis of full-load engine performance was conducted to assess the impact of using hemp oil methyl esters (HME) and rapeseed oil methyl esters (RME) as alternative fuels compared to conventional diesel fuel (DF). The experimental campaign involved steady-state measurements of torque and brake power across a wide range of engine speeds under wide-open throttle (WOT) conditions. Two comparative perspectives are presented: the first between HME and DF, and the second between RME and HME.

Figure 3 illustrates the torque and power characteristics of the engine fueled with DF and HME. The upper part of the figure shows the absolute torque and power curves of both fuels, while the lower section presents the percentage change of the HME results relative to those of DF. This dual representation allows a comprehensive evaluation of both absolute and relative performance effects. At engine speeds below 2200 rpm, HME yielded slightly higher torque and power outputs compared to DF, with peak improvements of +4.6% in torque and a mean increase of +0.91%. These gains can be attributed to favorable combustion characteristics at low load conditions, where the oxygen content of the biodiesel facilitates more complete combustion despite lower air availability. Moreover, the reduced viscosity of HME likely improves atomization and mixing, leading to more homogeneous air–fuel preparation and a faster ignition process.
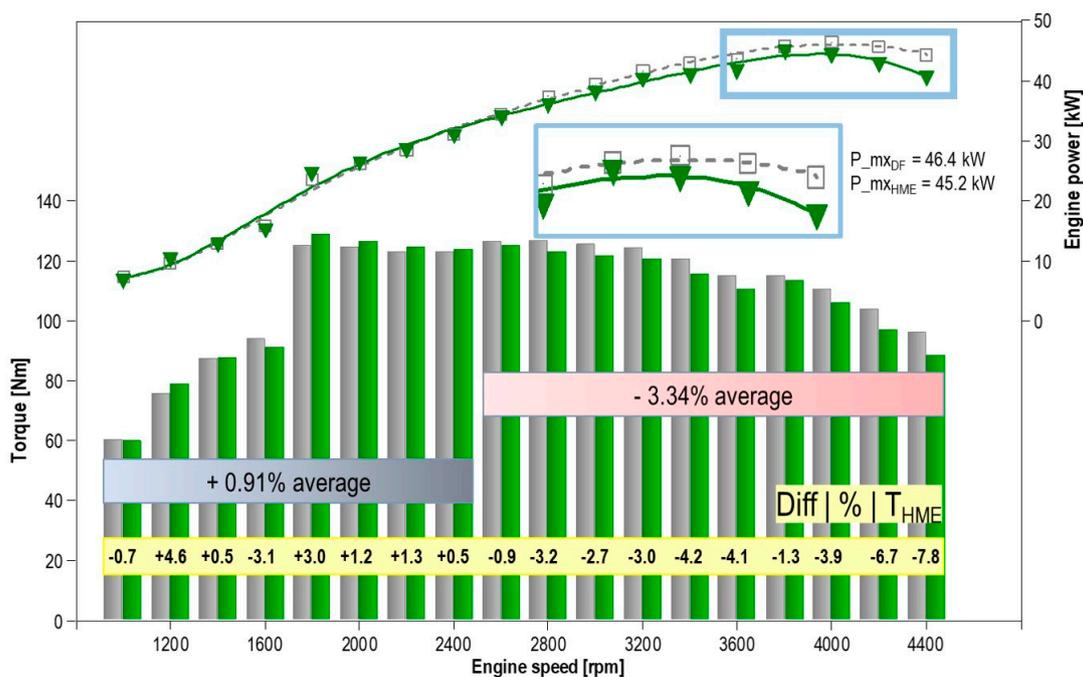
Figure 3. Torque full-load characteristics of engine powered by DF (grey) and HME (green) fuel.

As engine speed increased, however, the performance advantage of HME diminished. Beyond 2600 rpm, HME consistently underperformed in comparison to DF, with an average torque loss of −3.34%. The maximum brake power was achieved at 4000 rpm for both fuels; however, DF reached 46.4 kW, while HME delivered only 45.2 kW—a 3.9% reduction. This power shortfall may be related to the intrinsic physicochemical properties of HME, including its fatty acid methyl ester profile, oxidative stability, and cetane number. These parameters influence fuel ignition delay and combustion phasing, particularly under high-temperature, high-airflow conditions that dominate the upper-speed engine operation.

To further explore the suitability of HME in comparison to other biodiesels, Figure 4 presents a direct performance comparison between HME and RME. The diagram shows the relative differences in power and torque between HME and RME. In the lower-speed range (up to approximately 2200 rpm), both fuels demonstrate relatively comparable performance, with minor fluctuations. HME shows localized advantages in torque at several operating points, but these are not consistent. Notably, at engine speeds of up to 1800 rpm, RME exceeds HME by up to −9.5% in power and −7.1% in torque. Operation at full load and engine speeds below 1200 rpm represents a challenging operating condition for compression ignition engines. Due to increased cycle-to-cycle variability and combustion instability, the results in this range lack repeatability and are excluded from trend analysis.

In the mid- and high-speed ranges (from 2800 to 4400 rpm), RME increasingly outperforms HME. The performance gap widens progressively, culminating in a maximum power deficit of −8.6% and torque deficit of −8.5% for HME at 4400 rpm.

In the speed range of 1800 to 2400 rpm, HME shows an improvement in both torque and power compared to RME, with maximum differences of +4.8% in power and +2.9% in torque. Outside this range, RME consistently outperforms HME, especially at higher engine speeds. These results indicate that HME may offer local benefits, but its application is limited by reduced performance at medium-to-high speeds.

The differences observed between HME and RME underscore the importance of tailoring fuel formulations to specific engine operating areas. While both fuels are chemically oxygenated and derived from renewable sources, their differing physical and chemical properties yield markedly different engine responses.
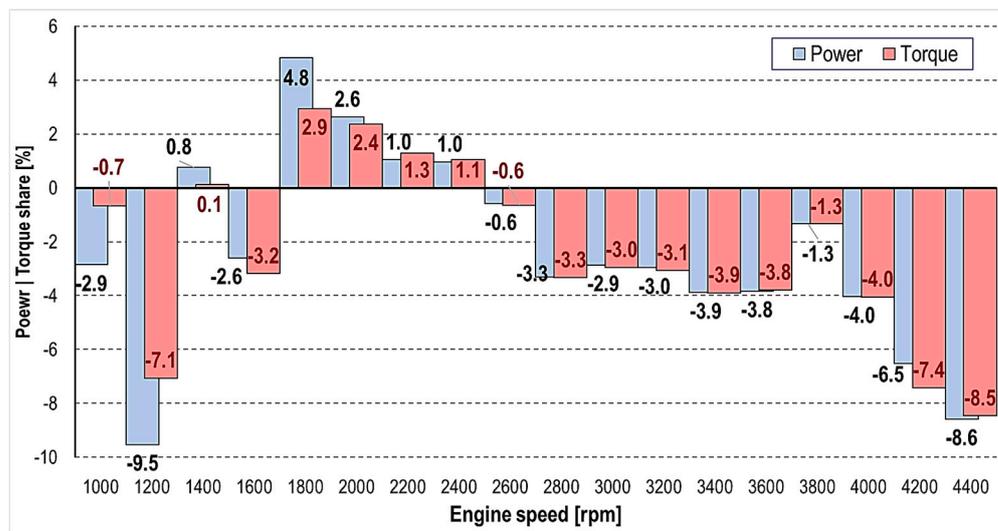
Figure 4. Engine performance differential between HME and RME.

3.2. Fuel Consumption in Terms of Oxygen Content in Biofuels

As an indicator of the overall energy conversion efficiency of the engine, the brake-specific fuel consumption (BSFC) was selected for analysis. Figure 5 presents the full-load BSFC characteristics of HME and DF, together with the percentage difference in BSFC values for HME compared to the reference DF. Figure 6, in turn, shows a direct comparison between HME and RME, with the percentage change in BSFC of HME indicated on a secondary axis.
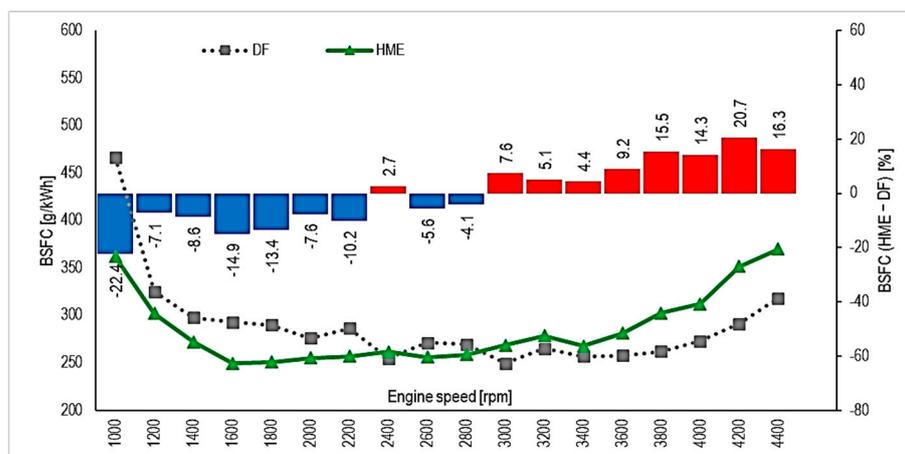

Figure 5. Brake-specific fuel consumption characteristics of DF and HME, and resulting difference between HME and DF.

In the low-speed range (1000–1200 rpm), the engine operates under thermodynamically unstable and less efficient conditions. This is reflected by significantly elevated BSFC values and greater variability. At 1000 rpm, HME exhibited a 22.4% higher BSFC than DF, indicating low combustion efficiency and increased fuel demand at very low engine speeds. Similar behavior was observed during comparison with RME, where HME demonstrated a 16.5% higher BSFC at the same speed.

In the medium-speed range (2200–3000 rpm), the brake-specific fuel consumption (BSFC) of HME and DF was comparable, averaging approximately 260 g/kWh. The minimum BSFC for HME was recorded at 249.3 g/kWh at 1600 rpm, while for DF the lowest value was 249.7 g/kWh, observed at 2400 rpm. During the comparison with RME,

HME also demonstrated slightly better BSFC in the low- and mid-speed ranges, with a maximum advantage of −8.7% at 1800 rpm. However, these advantages are temporary and limited to a narrow range of engine speeds. As engine speed increases beyond 3000 rpm, the thermodynamic load on the engine increases, airflow improves due to turbocharger dynamics, and combustion becomes more rapid. Under these conditions, DF and RME begin to outperform HME. For instance, at 3800 rpm, the BSFC of HME was 15.5% higher than that of DF. Similarly, in the HME vs. RME comparison, the maximum increase of BSFC for HME was 15.5% at 3600 rpm. The minimum values of BSFC were measured in the region of 1600–2600 rpm, where combustion and air–fuel mixing are most effective for all fuels tested.

The results clearly demonstrate that while HME can achieve comparable or even improved fuel efficiency in the mid-speed range, its performance deteriorates under high-speed conditions. This is likely due to limitations in vaporization dynamics, viscosity effects, and combustion propagation speed, particularly at elevated airflow rates.
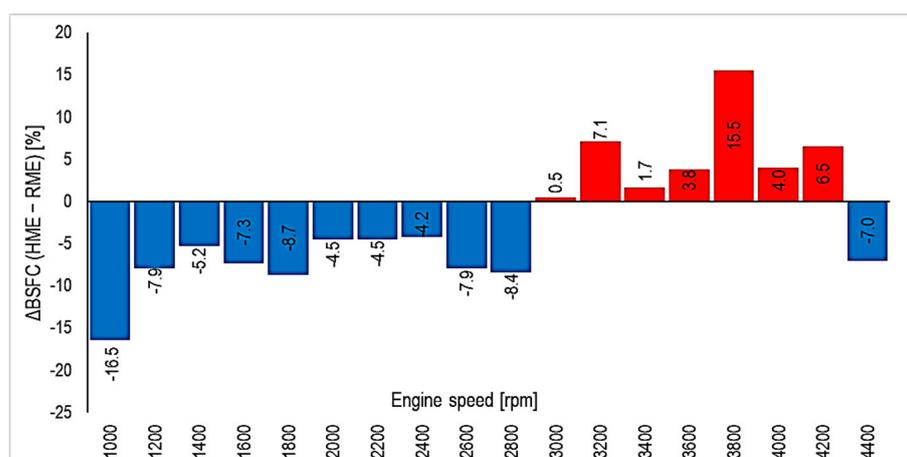

Figure 6. Brake-specific fuel consumption characteristics of RME and HME, and resulting difference between HME and RME.

3.3. Exhaust Gas Composition

The evaluation of pollutant emissions was conducted using an engine equipped with its original exhaust aftertreatment system. Exhaust gas was sampled downstream of the diesel two-way catalyst and diesel particulate filter (DPF), ensuring the assessment of real post-treatment values. Emission characteristics were analyzed for three regulated components: nitrogen oxides (NO_x), unburned hydrocarbons (HC), and smoke opacity converted to PMc. Figure 7 presents the results for HME compared to DF, while Figure 8 shows a comparison between HME and RME.
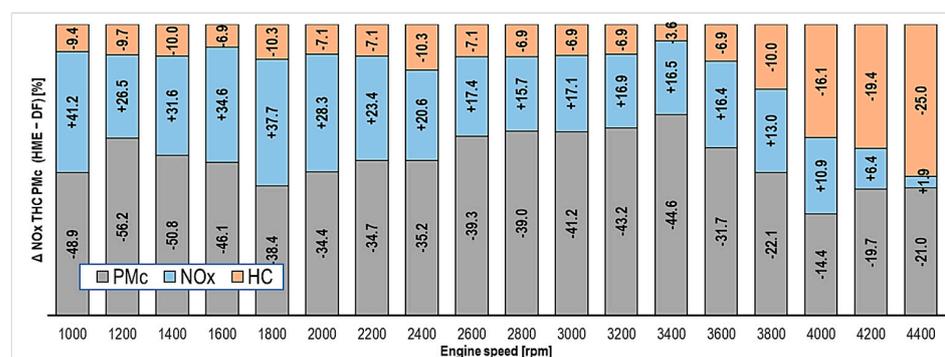

Figure 7. Changes in NO_x, THC, and smoke emissions of HME relative to DF.
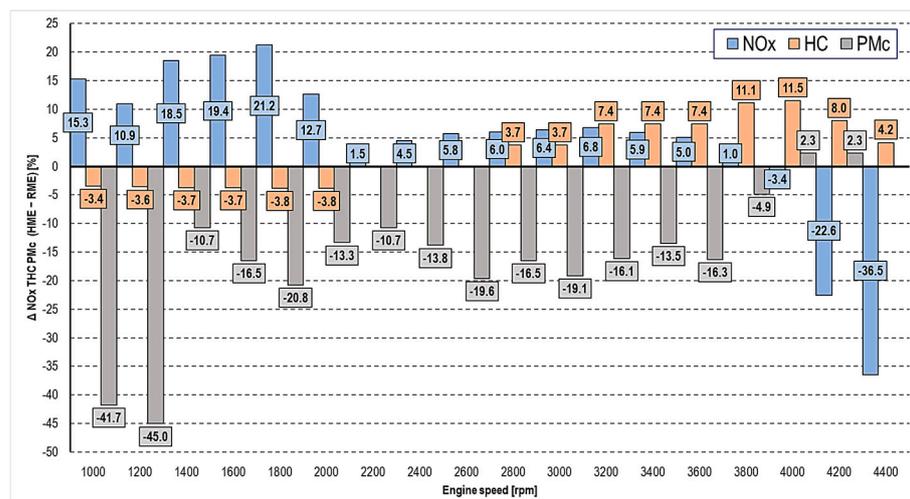
Figure 8. Changes in NO_x, THC, and smoke emissions of HME relative to RME.

In the low-speed range (1000–1600 rpm), HME achieved a significant reduction in smoke opacity, with peak improvements of up to −56.2% at 1200 rpm compared to DF. The lower soot formation observed for HME is primarily attributed to its oxygenated chemical structure and the absence of aromatics, which together promote more complete combustion and enhance soot oxidation even under low in-cylinder pressure levels. However, in the same speed range, the NO_x emissions of HME exceeded those of DF, reaching +26.5% at 1200 rpm and up to +44.2% at 1000 rpm. This increase is consistent with the higher flame temperatures associated with the use of biofuels due to their faster ignition and combustion kinetics [49]. HC emissions remained modest, staying below +10% across this range. In the medium-speed range (2000–3000 rpm), the emission profile of HME became more balanced. Smoke opacity continued to be significantly reduced (−34.7% to −39.3%), while NOx emission levels stabilized at around +15.7 to +17.4%. The HC emissions of HME remained relatively constant at approximately +7.1%, with only minor variations. At high engine speeds (above 3200 rpm), the advantages of HME in terms of soot reduction persisted, with smoke opacity reductions of between −41.2% and −44.6% compared to DF. Nevertheless, both NO_x and HC emissions increased sharply. The NO_x values of HME exceeded those of DF by up to +25.0% at 4400 rpm, and HC emissions rose progressively, reaching +16.4% at 3600 rpm and +19.4% at 4200 rpm. This pattern likely reflects the thermal and air flow limitations encountered at high loads, where the fast-reacting HME induces higher combustion temperatures without the same control of ignition timing as diesel. RME and HME fuels have a COOH carboxyl group containing oxygen. DF does not contain oxygen. With more oxygen available in the combustion chamber, less PM and HC are emitted. Unfortunately, in some cases, a higher amount of oxygen in the fuel probably causes an increase in the temperature in the combustion chamber and increases the conversion of nitrogen into NOx. Figure 8 shows that there is probably more oxygen in HME than in RME.

When comparing HME with RME (Figure 8), HME demonstrated superior performance in reducing smoke opacity at almost all operating points. At 1400 rpm, the smoke opacity of HME was 45.0% lower than that of RME, and at high speeds (4000–4400 rpm), this advantage remained significant, at 22.6 to 36.5%. However, HME exhibited higher NO_x emissions than RME across most speeds, peaking at +19.4% at 1400 rpm. This confirms the influence of fuel composition and cetane number on NO_x formation—RME generally promotes cooler combustion due to its higher ignition quality [4,5]. Regarding HC emissions, HME showed better results than RME in the low- and mid-speed ranges (e.g., −3.8% at 2000–2400 rpm), but emitted more unburned HC at higher speeds, with +11.5% at

4000 rpm and +8.0% at 4200 rpm. These results correlate with the torque drops and combustion variability observed under high engine speeds. In summary, the use of HME results in a highly favorable smoke opacity profile, clearly outperforming both DF and RME. However, these benefits are accompanied by elevated NO_x emissions, particularly at low and high loads, and higher HC emissions during high-speed operation. These outcomes reflect the combustion behavior typical of oxygenated fuels and highlight the necessity of advanced calibration strategies, such as adjusted injection timing or EGR application, to fully leverage the benefits of HME.

4. Discussion of Results

This study aimed to identify the effects of using rapeseed oil methyl esters and hemp oil to fuel a compression ignition internal combustion engine. Much research has focused on powering engines with RME, and the effects are quite well recognized. The opposite is true for the combustion of HME, where the amount of research is negligible, as highlighted in the work of Yilbasi et al. [55].

Considering the torque generated, better results were obtained using biofuels, especially RME, in the low-speed range. When successively increasing the rotational speed, higher torque values were generated by the engine powered by conventional fuel. A paper on the co-firing of biofuels with gaseous fuels [56] presented identical characteristics. When analyzing the HME engine feed, a deterioration in performance was noted. The lowest specific fuel consumption was recorded for HME, followed by RME and DF in the low and medium speed ranges. A further reduction in fuel consumption was shown for DF. In a paper [57] exploring an engine speed of 3000 rpm, the specific fuel consumption of DF and RME was compared. Over a wide load range, higher consumption was found for RME. The characteristics presented in another work [58] show similar trends.

Regarding the emissions of the selected exhaust components, using biofuels in the study presented here results in increased NO_x emissions and decreased HC, CO_2, and smoke. Kawano et al.'s study [58] conducted on a four-cylinder engine showed that, as the proportion of RME in the mixture increases, specific NO_x emissions increase, HC decreases, and BSFC increases. In a paper by Tsolakis et al. [59] it was reported that, for engine loads of 4.5 bar and 6.1 bar, the concentration of NO_x in the exhaust increases with the proportion of RME in the mixture. The same paper also presented the positive effects of reducing hydrocarbon concentrations as the proportion of RME in the fuel increases. Mamat et al. [60] came to the same conclusions by studying a six-cylinder engine running at 1550 rpm. The use of RME to fuel a 1.3 JTD engine during a 13-phase ESC test in the work of [61] resulted in a reduction in smoke as the proportion of RME in the fuel increased.

Analyzing the pressure waveform and its derivatives showed reductions in the maximum in-cylinder pressure, the heat release rate, and the amount of heat released for biofuels, especially HME. However, using biofuels accelerated the initiation of the combustion process, which translated into an earlier achievement of the MBF50 combustion center. Accelerated combustion initiation for biofuels was presented in the work of Chen et al. [62]. They described a reduction in ignition delay with an engine speed of 1500 rpm and a load of 0.2 to 1.3 MPa. The cylinder pressure waveforms for RME and diesel at 2500 rpm and with a full engine load, presented by Beatrice [63], and at 2000 rpm and with a full load, presented in the work of Magno et al. [64,65], indicate a reduction in cylinder pressure with RME.

A study of hemp oil methyl esters' use as engine fuels was undertaken by Zeki Yilbasi et al. [55]. A single-cylinder engine running at a constant speed of 1500 rpm was used. The load characteristic results were presented, and, for comparison, all tests were repeated with the DF reference fuel. As the proportion of hemp fuel increased, the value of

maximum cylinder pressure decreased from 85 to 80 bar. The trend continued sequentially for the heat release rate and the amount of heat released. The exhaust emissions analysis showed increased NO_x emissions for the HME, which increased with increasing load, and a significant reduction in HC and smoke over the entire load range.

5. Summary and Conclusions

This study comparing the performance of an engine fueled by fuel obtained from hemp HME and fuel from rapeseed RME against the reference fuel, DF, found significant differences in engine performance. The following conclusions were reached:

- With limited oxygen, the low charge dynamics for HME and RME increased the maximum torque at around 1900 rpm. For HME, the increase in maximum torque relative to DF was 12%. These relationships were reversed at higher speeds of up to 4000 rpm. As a result, the HME-fueled engine had about 4% less maximum power. The authoritative indicator is BSFD. Specific fuel consumption was lower for biofuels at low speeds of up to 2500 rpm, while at higher speeds, the relationship was reversed. This is due to the large difference in fuel density and heating value.

- The level of exhaust emissions differed significantly. For NO_x emissions, an average increase of 17% was found for biofuels. Other parameters were reduced: HC was lower relative to DF, while the ratio of HME to RME was variable. For speeds of up to 2500 rpm, significantly lower emissions were observed for HME, though the opposite occurred at higher speeds. The use of biofuels results in an effective reduction in soot in the exhaust gas. The amount of smoke in the exhaust gas decreased by an average of 24% relative to DF and was lowest when using HME.

Thermodynamic changes in the combustion chamber were also significantly different. The use of HME reduced the amount of heat released by 12.5%, which translated into a reduction in cylinder pressure at a similar level. However, a shift in the extremum of the pressure function of 3° CA aTD was observed. This is due to the presence of oxygen in the fuel, which increases heat release dynamics in the first phase of combustion.

Fuel diversification is important for increasing energy security and reducing environmental impact. The presented research results confirm that the JTD engine operated correctly on 100% HME without the need for equipment modifications, showing only slight differences in performance compared to diesel fuel. At the same time, HME retains the basic advantages of biodiesel, including reduced soot emissions and favorable combustion properties, due to its oxygen-containing structure. In the future, our research will focus on testing biofuels derived from HME on other engine types with different power outputs and displacements to verify the obtained results across a wider range of applications. It is also recommended to analyze the influence of various operating conditions and to assess the long-term performance of engines fueled with HME and RME. These steps will allow for a more comprehensive evaluation of the practical potential of biofuels in automotive applications.

The results of the performed study confirm the possibility of using hemp oil as an alternative to the commonly used RME. Slight differences in engine performance do not translate into engine operation.

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References

1. Czwartkowski, K.; Wierzbic, A.; Golimowski, W. Awareness and Expectations of Polish Consumers Regarding Edible Niche Oils as a Food Product. *Sustainability* **2022**, *14*, 14239. [CrossRef]
2. Fike, J. Industrial Hemp: Renewed Opportunities for an Ancient Crop. *CRC Crit. Rev. Plant Sci.* **2016**, *35*, 406–424. [CrossRef]
3. Lin, Y.; Pangloli, P.; Dia, V.P. Physicochemical, Functional and Bioactive Properties of Hempseed (*Cannabis sativa* L.) Meal, a Co-Product of Hempseed Oil and Protein Production, as Affected by Drying Process. *Food Chem.* **2021**, *350*, 129188. [CrossRef]
4. Mikulec, A.; Kowalski, S.; Sabat, R.; Skoczylas, Ł.; Tabaszewska, M.; Wywrocka-Gurgul, A. Hemp Flour as a Valuable Component for Enriching Physicochemical and Antioxidant Properties of Wheat Bread. *LWT* **2019**, *102*, 164–172. [CrossRef]
5. Baeck, S.; Kim, B.; Cho, B.; Kim, E. Analysis of Cannabinoids in Urine Samples of Short-Term and Long-Term Consumers of Hemp Seed Products. *Forensic Sci. Int.* **2019**, *305*, 109997. [CrossRef]
6. Tura, M.; Mandrioli, M.; Valli, E.; Rubino, R.C.; Parentela, D.; Toschi, T.G. Changes in the Composition of a Cold-Pressed Hemp Seed Oil during Three Months of Storage. *J. Food Compos. Anal.* **2022**, *106*, 104270. [CrossRef]
7. Da Porto, C.; Decorti, D.; Tubaro, F. Fatty Acid Composition and Oxidation Stability of Hemp (*Cannabis sativa* L.) Seed Oil Extracted by Supercritical Carbon Dioxide. *Ind. Crops Prod.* **2012**, *36*, 401–404. [CrossRef]
8. Mnekin, L.; Ripoll, L. Topical Use of *Cannabis sativa* L. Biochemicals. *Cosmetics* **2021**, *8*, 85. [CrossRef]
9. Teh, S.S.; Bekhit, A.E.D.A.; Carne, A.; Birch, J. Antioxidant and ACE-Inhibitory Activities of Hemp (*Cannabis sativa* L.) Protein Hydrolysates Produced by the Proteases AFP, HT, Pro-G, Actinidin and Zingibain. *Food Chem.* **2016**, *203*, 199–206. [CrossRef]
10. Lin, Y.; Pangloli, P.; Meng, X.; Dia, V.P. Effect of Heating on the Digestibility of Isolated Hempseed (*Cannabis sativa* L.) Protein and Bioactivity of Its Pepsin-Pancreatin Digests. *Food Chem.* **2020**, *314*, 126198. [CrossRef]
11. Fayyazbakhsh, A.; Bell, M.L.; Zhu, X.; Mei, X.; Koutný, M.; Hajinajaf, N.; Zhang, Y. Engine Emissions with Air Pollutants and Greenhouse Gases and Their Control Technologies. *J. Clean. Prod.* **2022**, *376*, 134260. [CrossRef]
12. Hemmerlein, N.; Korte, V.; Richter, H.; Schröder, G. Performance, Exhaust Emissions and Durability of Modern Diesel Engines Running on Rapeseed Oil. *SAE Trans.* **1991**, *100*, 400–415.
13. Golimowski, W.; Pasyniuk, P.; Berger, W.A. Common Rail Diesel Tractor Engine Performance Running on Pure Plant Oil. *Fuel* **2013**, *103*, 227–231. [CrossRef]
14. Altarazi, Y.S.M.; Abu Talib, A.R.; Yusaf, T.; Yu, J.; Gires, E.; Ghafir, M.F.A.; Lucas, J. A Review of Engine Performance and Emissions Using Single and Dual Biodiesel Fuels: Research Paths, Challenges, Motivations and Recommendations. *Fuel* **2022**, *326*, 125072. [CrossRef]
15. Go, A.W.; Sutanto, S.; Ong, L.K.; Tran-Nguyen, P.L.; Ismadji, S.; Ju, Y.H. Developments in In-Situ (Trans) Esterification for Biodiesel Production: A Critical Review. *Renew. Sustain. Energy Rev.* **2016**, *60*, 284–305. [CrossRef]
16. Thompson, W.; Meyer, S. Second Generation Biofuels and Food Crops: Co-Products or Competitors? *Glob. Food Sec.* **2013**, *2*, 89–96. [CrossRef]
17. Golimowski, W.; Berger, W.A.; Pasyniuk, P.; Rzeźnik, W.; Czechlowski, M.; Koniuszy, A. Biofuel Parameter Dependence on Waste Fats' Fatty Acids Profile. *Fuel* **2017**, *197*, 482–487. [CrossRef]
18. Adhikesavan, C.; Ganesh, D.; Augustin, V.C. Effect of Quality of Waste Cooking Oil on the Properties of Biodiesel, Engine Performance and Emissions. *Clean. Chem. Eng.* **2022**, *4*, 100070. [CrossRef]
19. Sakthimurugan, V.; Madhu, S. Novel Scenedesmus Obliquus Algae Biofuel Emission and Performance Characterise in Si-DLC Coated Diesel Engine. *Mater. Today Proc.* **2023**, *77*, 490–496. [CrossRef]
20. Lodi, F.; Zare, A.; Arora, P.; Stevanovic, S.; Ristovski, Z.; Brown, R.J.; Bodisco, T. Engine Performance Characteristics Using Microalgae Derived Dioctyl Phthalate Biofuel during Cold, Preheated and Hot Engine Operation. *Fuel* **2023**, *344*, 128162. [CrossRef]
21. Mehra, K.S.; Singh, S.; Singh, A.K.; Kharkwal, H.; Avikal, S. Performance, Energy, Emission and Cost Analysis of Jatropha (*Jatropha curcas*) Oil as a Biofuel for Compression Ignition Engine. *Mater. Today Proc.* **2020**, *43*, 348–354. [CrossRef]
22. Venkatesan, S.P.; Rahul, R.; Sabbharishi, V.; Purusothamand, M.; Ganesan, S. Study of Emission Characteristics of a Diesel Engine Run by Fuel Blends of Diesel, Jatropha Biodiesel and Cetane Improver. *Mater. Today Proc.* **2023**, in press. [CrossRef]
23. Rajpoot, A.S.; Choudhary, T.; Chelladurai, H.; Mishra, S.; Shende, V. Performance Analysis of a CI Engine Powered by Different Generations of Biodiesel; Palm Oil, Jatropha, and Microalgae. *Mater. Today Proc.* **2023**, in press. [CrossRef]
24. Nagappan, M.; Babu, J.M. In Ternary Blend Fuelled Diesel Engines, Nanoparticles Are Used as an Additive in Biofuel Production and as a Fuel Additive: A Review. *Mater. Today Proc.* **2023**, in press. [CrossRef]

25. Gad, M.S.; Ağbulut, Ü.; Afzal, A.; Panchal, H.; Jayaraj, S.; Qasem, N.A.A.; El-Shafay, A.S. A Comprehensive Review on the Usage of the Nano-Sized Particles along with Diesel/Biofuel Blends and Their Impacts on Engine Behaviors. *Fuel* **2023**, *339*, 127364. [CrossRef]

26. Yildiz, I.; Caliskan, H.; Mori, K. Assessment of Biofuels from Waste Cooking Oils for Diesel Engines in Terms of Waste-to-Energy Perspectives. *Sustain. Energy Technol. Assess.* **2022**, *50*, 101839. [CrossRef]

27. Viswanathan, K.; Taipabu, M.I.; Wu, W. Novel Petit Grain Bitter Orange Waste Peel Oil Biofuel Investigation in Diesel Engine with Modified Fuel Injection Pressure and Bowl Geometry. *Fuel* **2022**, *319*, 123660. [CrossRef]

28. Kabudke, P.D.; Kharde, Y.R.; Parkhe, R.A. Experimental Investigation on Performance of Cotton Seed Biofuel Blended with Diesel on Variable Compression Ratio Diesel Engine. *Mater. Today Proc.* **2023**, *72*, 846–852. [CrossRef]

29. Asokan, M.A.; Prabu, S.S.; Bollu, A.; Reddy, M.A.; Ram, A.; Sukhadia, D.S. Emission and Performance Behavior of Hemp Seed Oil Biodiesel/Diesel Blends in Di Diesel Engine. *Mater. Today Proc.* **2021**, *46*, 8127–8132. [CrossRef]

30. Golimowski, W.; Teleszko, M.; Marcinkowski, D.; Kmiecik, D.; Grygier, A.; Kwaśnica, A. Quality of Oil Pressed from Hemp Seed Varieties: 'Ealina 8FC', 'Secueni Jubileu' and 'Finola'. *Molecules* **2022**, *27*, 3171. [CrossRef]

31. Razmaitė, V.; Šiukščius, A.; Leikus, R. Effects of Dietary Rapeseed (*Brassica napus*), Hemp (*Cannabis sativa*) and Camelina (*Camelina sativa*) Seed Cakes Supplementation on Yolk and Albumen Colour and Nutritional Value of Yolk Lipids in Estonian Quail Eggs. *Animals* **2022**, *12*, 3110. [CrossRef] [PubMed]

32. Kurczyński, D.; Wcisło, G. Producing and Testing the Properties of Biodiesel Sourced from Hemp Oil. *Energies* **2024**, *17*, 5950. [CrossRef]

33. Sienkiewicz, A.; Piotrowska-Niczyporuk, A.; Bajguz, A. Fatty Acid Methyl Esters from the Herbal Industry Wastes as a Potential Feedstock for Biodiesel Production. *Energies* **2020**, *13*, 3702. [CrossRef]

34. Addison, G.; Milligan, K.A.; Ohlig, S. Comparative Analysis of ZnO and CeO_2 Nanoparticle Additives for the Improvement of Hemp Biofuels as a Sustainable Biodiesel Alternative: A Comprehensive Review. *Ind. Crops Prod.* **2024**, *214*, 118480. [CrossRef]

35. Szulczyk, K.R.; Badeeb, R.A. Nontraditional Sources for Biodiesel Production in Malaysia: The Economic Evaluation of Hemp, Jatropha, and Kenaf Biodiesel. *Renew Energy* **2022**, *192*, 759–768. [CrossRef]

36. Verma, T.N.; Shrivastava, P.; Rajak, U.; Dwivedi, G.; Jain, S.; Zare, A.; Shukla, A.K.; Verma, P. A Comprehensive Review of the Influence of Physicochemical Properties of Biodiesel on Combustion Characteristics, Engine Performance and Emissions. *J. Traffic Transp. Eng.* **2021**, *8*, 510–533. [CrossRef]

37. Uslu, S.; Simsek, S.; Simsek, H. RSM Modeling of Different Amounts of Nano-TiO_2 Supplementation to a Diesel Engine Running with Hemp Seed Oil Biodiesel/Diesel Fuel Blends. *Energy* **2023**, *266*, 126439. [CrossRef]

38. Gaur, A.; Dwivedi, G.; Baredar, P.; Jain, S. Influence of Blending Additives in Biodiesel on Physiochemical Properties, Engine Performance, and Emission Characteristics. *Fuel* **2022**, *321*, 124072. [CrossRef]

39. Nagwan, H.; Bangari, R.S.; Singh, K.; Kumar, P. Study the Performance Characteristics of CI Engine with Hemp Oil Methyl Ester, Ethanol and Diesel Blends. *Mater. Today Proc.* **2023**, in press. [CrossRef]

40. Sultanbekov, R.; Denisov, K.; Zhurkevich, A.; Islamov, S. Reduction of Sulphur in Marine Residual Fuels by Deasphalting to Produce VLSFO. *J. Mar. Sci. Eng.* **2022**, *10*, 1765. [CrossRef]

41. Sultanbekov, R.; Beloglazov, I.; Islamov, S.; Ong, M.C. Exploring of the Incompatibility of Marine Residual Fuel: A Case Study Using Machine Learning Methods. *Energies* **2021**, *14*, 8422. [CrossRef]

42. Sultanbekov, R.; Islamov, S.; Mardashov, D.; Beloglazov, I.; Hemmingsen, T. Research of the Influence of Marine Residual Fuel Composition on Sedimentation Due to Incompatibility. *J. Mar. Sci. Eng.* **2021**, *9*, 1067. [CrossRef]

43. *ISO 8178-1*; Reciprocating Internal Combustion Engines—Exhaust Emission Measurement. International Organization for Standardization: Geneve, Switzerland, 2020.

44. Wołoszyn, J.; Haraf, G.; Okruszek, A.; Wereńska, M.; Goluch, Z.; Teleszko, M. Fatty Acid Profiles and Health Lipid Indices in the Breast Muscles of Local Polish Goose Varieties. *Poult. Sci.* **2020**, *99*, 1216–1224. [CrossRef]

45. Ramírez-Verduzco, L.F.; Rodríguez-Rodríguez, J.E.; Jaramillo-Jacob, A.D.R. Predicting Cetane Number, Kinematic Viscosity, Density and Higher Heating Value of Biodiesel from Its Fatty Acid Methyl Ester Composition. *Fuel* **2012**, *91*, 102–111. [CrossRef]

46. Islam, M.A.; Magnusson, M.; Brown, R.J.; Ayoko, G.A.; Nabi, M.N.; Heimann, K. Microalgal Species Selection for Biodiesel Production Based on Fuel Properties Derived from Fatty Acid Profiles. *Energies* **2013**, *6*, 5676–5702. [CrossRef]

47. Hawrot-Paw, M.; Ratomski, P.; Koniuszy, A.; Golimowski, W.; Teleszko, M.; Grygier, A. Fatty Acid Profile of Microalgal Oils as a Criterion for Selection of the Best Feedstock for Biodiesel Production. *Energies* **2021**, *14*, 7334. [CrossRef]

48. Deshmukh, S.; Bala, K.; Kumar, R. Selection of Microalgae Species Based on Their Lipid Content, Fatty Acid Profile and Apparent Fuel Properties for Biodiesel Production. *Environ. Sci. Pollut. Res.* **2019**, *26*, 24462–24473. [CrossRef] [PubMed]

49. Gongping, M.; Zhong, W.; Peng, H.; Peiyong, N.; Xiaozhe, W.; Shi-Qiang, G. Experimental Research on the Flame Temperature of Biodiesel Fuel Combustion in Open-air Conditions. In Proceedings of the 2011 International Conference on Electric Information and Control Engineering (ICEICE 2011), Wuhan, China, 15–17 April 2011.

50. *OIML R99-1 & 2:2008 (reconfirmed 2024)*; Instruments for Measuring Vehicle Exhaust Emissions—Part 1: Metrological and Technical Requirements; Part 2: Metrological Control and Performance Tests. International Organization of Legal Metrology: Paris, France, 2008.

51. *ISO 3930/PAS 3930:2009*; Instruments for Measuring Vehicle Exhaust Emissions—Metrological and Technical Requirements. International Organization for Standardization: Geneva, Switzerland, 2009.

52. *BAR-97*; Emissions Inspection System Specifications. California Bureau of Automotive Repair: Sacramento, CA, USA, 2017.

53. *Directive 2014/32/EU*; The Harmonisation of the Laws of the Member States Relating to the Making Available on the Market of Measuring Instruments (Measuring Instruments Directive, MID). European Parliament and Council: Brussels, Belgium, 2014.

54. *ISO 1585:2020*; Road Vehicles—Engine Test Code—Net Power. International Organization for Standardization: Geneva, Switzerland, 2020.

55. Yilbaşi, Z.; Yesilyurt, M.K.; Yaman, H.; Arslan, M. The Industrial-Grade Hemp (*Cannabis sativa* L.) Seed Oil Biodiesel Application in a Diesel Engine: Combustion, Harmful Pollutants, and Performance Characteristics. *Sci. Technol. Energy Transit. (STET)* **2022**, *77*, 15. [CrossRef]

56. Gracz, W.; Marcinkowski, D.; Golimowski, W.; Szwajca, F.; Strzelczyk, M.; Wasilewski, J.; Krzaczek, P. Multifaceted Comparison Efficiency and Emission Characteristics of Multi-Fuel Power Generator Fueled by Different Fuels and Biofuels. *Energies* **2021**, *14*, 3388. [CrossRef]

57. Nwafor, O.M.I.; Rice, G. Performance of Rapeseed Methyl Ester in Diesel Engine. *Renew. Energy* **1995**, *6*, 335–342. [CrossRef]

58. Kawano, D.; Ishii, H.; Goto, Y. Effect of Biodiesel Blending on Emission Characteristics of Modern Diesel Engine. *SAE Tech. Pap.* **2008**, *1*, 2384–2392.

59. Tsolakis, A.; Megaritis, A.; Wyszynski, M.L.; Theinnoi, K. Engine Performance and Emissions of a Diesel Engine Operating on Diesel-RME (Rapeseed Methyl Ester) Blends with EGR (Exhaust Gas Recirculation). *Energy* **2007**, *32*, 2072–2080. [CrossRef]

60. Mamat, R.; Abdullah, N.R.; Xu, H.; Wyszynski, M.; Tsolakis, A. *Effect of Fuel Temperature on Performance and Emissions of a Common Rail Engine Operating with Rapeseed Methyl Ester (RME)*; SAE Technical Paper 2009-01-1896; SAE International: Warrendale, PA, USA, 2009.

61. Merkisz, J.; Kozak, M.; Pielecha, J.; Andrzejewski, M. The Influence of Application of Different Diesel Fuel-RME Blends on PM Emissions from a Diesel Engine. *Combust. Engines* **2012**, *1*, 35. [CrossRef]

62. Chen, H.; Xie, B.; Ma, J.; Chen, Y. NOx Emission of Biodiesel Compared to Diesel: Higher or Lower? *Appl. Therm. Eng.* **2018**, *137*, 584–593. [CrossRef]

63. Beatrice, C.; Guido, C.; Di Iorio, S.; Napolitano, P.; Del Giacomo, N. Impact of RME and GTL Fuel on Combustion and Emissions of a "Torque-Controlled" Diesel Automotive Engines. *SAE Int. J. Fuels Lubr.* **2010**, *3*, 118–134. [CrossRef]

64. Magno, A.; Mancaruso, E.; Vaglieco, B.M. *Endoscopic Investigation of Combustion Process in a Small Compression Ignition Engine Fuelled with Rapeseed Methyl Ester*; SAE Technical Paper 2014-01-2649; SAE International: Warrendale, PA, USA, 2014.

65. Magno, A.; Mancaruso, E.; Vaglieco, B.M. Analysis of Combustion Phenomena and Pollutant Formation in a Small Compression Ignition Engine Fuelled with Blended and Pure Rapeseed Methyl Ester. *Energy* **2016**, *106*, 618–630. [CrossRef]