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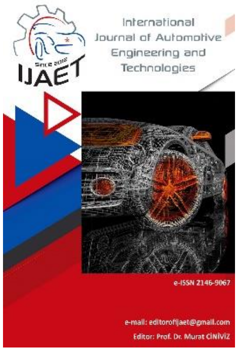

Original Research Article

Impact of turnip biodiesel-diesel blends on engine performance and fuel properties: a comparative analysis

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ABSTRACT

The imperative for alternative energy sources has become increasingly evident due to the rising impacts of climate change and greenhouse gas emissions. Biodiesel has emerged as a prominent contender among alternative fuels, offering advantages such as low toxicity, biodegradability, and favorable emission profiles. However, its production faces significant cost burdens, mainly from the expense of vegetable oil. Mustard, with its high oil content in seeds, presents a promising alternative oil source for biodiesel production. This study evaluates the effects of blending biodiesel derived from Brassica rapa ssp. Oil turnip seeds with diesel fuel on fuel properties and engine performance. Transesterification was employed for biodiesel production, and experimental fuels were prepared with varying biodiesel ratios. Engine performance tests, energy analyses, and uncertainty analyses were conducted, revealing a decrease in torque, power, and an increase in specific fuel consumption with higher biodiesel ratios. Energy analysis showed an increase in fuel energy flow with engine speed. Overall, the study contributes to the understanding of Brassica rapa biodiesel production and its application in internal combustion engines.

Keywords: biodiesel, energy analyses, engine performance, diesel engine,fuel properties.

1. Introduction

In contemporary times, the imperative for the development of alternative energy sources has been underscored by the escalating impacts of climate change and the concomitant rise in greenhouse gas emissions. This pressing need is further compounded by the swift depletion of fossil fuel reservoirs [1-2] and the enactment or prospective enactment of legislative measures aimed at curbing vehicular exhaust emissions, prompting numerous scholars to delve into the exploration of alternative fuel utilization modalities [3]. Biodiesel has emerged as a prominent contender among alternative fuels, with blends of biodiesel and diesel fuel garnering significant popularity. Renowned for its applicability in internal combustion engines, biodiesel offers distinct advantages over other forward-looking alternative fuels owing to its attributes of low toxicity, biodegradability, favorable lubricating properties, and commendable emission profiles [4-5]. However, the production of biodiesel is beset by significant cost burdens, primarily stemming from the production expenses associated with vegetable oil. Notably, the procurement of seeds, constituting 78% of biodiesel production costs, accounts for a substantial portion of the overall expenditure [6]. Predominantly, palm oil (Elaeis oliefera), soybean (Glycine max), sunflower (Helianthus annuus), and rapeseed (Brassica napus) represent the lion's share of global oil production, collectively exceeding 80% [7-8]. These crops, primarily cultivated for alimentary purposes, potentially engender competition between biodiesel production and food provision sectors. Furthermore, the utilization of non-edible oils for biodiesel synthesis is constrained by the indirect impact on food production resultant from the utilization of arable land [3]. Consequently, researchers are increasingly exploring avenues beyond traditional food manufacturing sectors in pursuit of alternative high-quality oil sources for biofuel applications [7-8]. One such promising source is mustard, an ancient spice dating back to antiquity. With a rich historical legacy tracing back 3000 years [9], mustard finds versatile application in both culinary and industrial domains, particularly within the spice and energy sectors. Key species within the mustard genus, including Sinapis alba syn., Brassica alba, S. arvensis syn. B. arvensis, B. juncea, B. rapa syn. B. campestris, and B. nigra, constitute integral components of Turkey's indigenous flora [10]. These species boast diverse compositions, featuring glycosides, arachidic acid, sinabin, lignoceric acid, among other compounds, in their oils. Notably, the pronounced presence of erucic acid renders these oils unsuitable for culinary purposes [11]. Previous investigations have revealed a significantly elevated percentage (25-35%) of seed oil within Turkey's mustard flora [12-14]. In light of these findings, it is evident that mustard holds considerable promise as a viable alternative oil source for biodiesel production. Addressing the burgeoning cost concerns associated with biodiesel manufacturing necessitates innovative approaches that capitalize on the unique attributes of mustard and other non-traditional oil sources, thereby fostering sustainable advancements within the realm of biofuel production. Eryilmaz and Öğüt (2011) [15] conducted a study to examine the performance impacts of various blending ratios of mustard oil biodiesel in a diesel engine. The formulated fuels were evaluated in a four stroke, three cylinders, 60 HP, direct injection diesel engine, and compared with conventional diesel fuel in terms of torque, power, fuel consumption, and smoke density. It was elucidated that the maximum torque for all fuel blends, namely B_{100}, B_{20}, and B_2, was observed at 1200 min^{-1}. The investigations involving diesel, B_{100}, B_{20}, and B_2 blends yielded the highest overall efficiencies of 34.348% at 1300 min^{-1}, 36.103% at 2000 min^{-1}, 36.911% at 1200 min^{-1}, and 34.565% at 1200 min^{-1}, respectively. It was noted that as the blending ratios increased, the exhaust smoke emissions exhibited greater reductions across all engine speeds when compared to conventional diesel fuel. Aysal et al. (2014) [16] examined the impact of biodiesel fuel derived from mustard oil-diesel blends at different proportions on engine performance and exhaust emissions. With increasing biodiesel ratio, there was a decrease in both power and torque output of the internal combustion engine, accompanied by a rise in SFC. Furthermore, comparisons were made among the NO_x and CO emissions of biodiesel, diesel fuels, and biodiesel-diesel fuel blends. It was observed that the emission values of mustard oil biodiesel were lower than those of diesel fuel. Bannikov (2011) [17] investigated the combustion and emission characteristics of biodiesel derived from mustard oil in a single-cylinder, 4-stroke, direct injection, naturally aspirated, 5 kW, air-cooled diesel engine, and compared them with those of diesel fuel. The findings revealed that the utilization of mustard oil biodiesel led to an increase in specific fuel consumption, a decrease in NO_x emissions and smoke density, a slight increase in CO emission, and no significant change in HC emission when compared to diesel fuel. Additionally, combustion analysis indicated that biodiesel usage resulted in earlier injection initiation, a shortened ignition delay period, a reduction in maximum heat release rate, and cylinder pressure. Yeşilyurt et al. (2019) [18] employed the CCD response surface methodology to optimize biodiesel production from yellow mustard seed oil. The study encompassed 30 experiments aimed at examining the effects of various variables on biodiesel yield. A second-degree polynomial model effectively forecasted the biodiesel yield, achieving a 96.695% yield under the optimized conditions. These findings underscored the efficacy of RSM in maximizing biodiesel yield through the fine-tuning of reaction parameters. Mitrovic et al. (2020) [19] undertook a study highlighting the potential favorable effects of white mustard oil-based biodiesel on sustainable development, akin to other oilseed crops. These effects encompass bolstering energy security, stimulating economic growth, and advocating environmental conservation. Nevertheless, the authors underscored the need for additional research and analysis to conduct a thorough comparison between white mustard oil and alternative feedstocks for biodiesel production.

The primary objective of this study is to evaluate the effects of blending biodiesel derived from Brassica rapa ssp. Oil turnip seeds, specifically the Br-2-Kaan variety candidate, with diesel fuel on fuel properties and engine performance. The central aim of this research is to assess the feasibility and energy efficiency of these biofuel blends. Emphasis is placed on the utilization of Brassica rapa ssp. Oil turnip seeds as an alternative source for biodiesel production. This plant species holds considerable significance due to its widespread presence in Turkey's natural flora and its high oil content in its seeds. The study investigates the impact of biodiesel fuel obtained from this plant on crucial parameters such as engine performance and energy analysis.

The contributions of this study to the field can be delineated as follows:

- It examines the viability of Brassica rapa ssp. oil turnip seeds as a potential alternative oil source for biodiesel production, emphasizing the significance of this plant within the bioenergy sector.
- Through the evaluation of engine performance, it investigates the energy efficiency and environmental ramifications of biodiesel-diesel fuel blends.

By employing methods such as energy analysis and uncertainty analysis, it provides a more comprehensive assessment of the energy balance and efficiency of biodiesel-diesel mixtures.

2. Materials and Method

Transesterification was employed for the production of biodiesel from Brassica Rapa oil at the pilot production facility established at Selçuk University Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering [20]. For biodiesel synthesis, a mixture comprising 20% crude Brassica Rapa oil, CH_3OH, and 3.5g NaOH per liter of oil was utilized to generate methoxide. The mixture underwent heating to 55 ºC, followed by the addition of methoxide, and an 8-hour incubation period for glycerol precipitation and subsequent separation. Subsequently, the temperature was raised to 75ºC to eliminate the remaining methyl alcohol from the crude biodiesel. Washing was carried out at 50ºC, with the wash water being separated from the methyl ester. Finally, the drying process at 100ºC yielded biodiesel. Material fuels were prepared by incorporating Brassica Rapa biodiesel at volumetric ratios of 5%, 10%, 20%, and 50% into diesel oil. Diesel fuel sourced from Shell, complying with EN 590 standards, was employed. The properties of the material fuels are comparatively illustrated in detailed in Table 1.

In the experiments, an internal combustion diesel engine with a power of 15 HP and torque of 60 Nm was utilized. The experiments were conducted in accordance with EN 1231 standards to measure specific fuel consumption, torque, and power values. The ester content of the biodiesel produced in this study is determined to be 96.5%.

3. Estimation of Uncertainty and Error Analysis

Uncertainty analysis is used in experimental studies to determine the accuracy and repeatability of data.

Table 1. Measurement results of material fuels

Typical	The Monads	Turnip Oil	B_{100}	D_{100}	$B_{50}D_{50}$	$B_{20}D_{80}$	$B_{10}D_{90}$	B_5D_{95}	Standards	
									EN 14214	ASTM D6751
Density (at 15°C)	g/cm^3	908.5	862.7	827.2	848.9	836.7	830.6	829.7	0.86-0.90	-
Kinematic Viscosity (at 40°C)	mm^2/s	42	5.9	2.9	3.96	3.47	3.26	3.01	3.5-5.0	1.9-6.0
pH	——	5	5	5	5	5	5	5	-	-
CFPP	°C	-12	-4	-11	-6	-7	-8	-9	-	Min. +5
Cloud Point	°C	-10	-1.5	-7.8	-3	-5	-6	-7.1	-	-3 to -12
Pour Point	°C	-15	-16	<-20	<-20	<-20	<-20	<-20	-	-15 to -16
Freezing Point	°C	-17	-18	<-20	<-20	<-20	<-20	<-20	-	-
Calorific Value	Cal/gr	-	9833	11053	10242	10869	10882	10906	-	-
Flash Point	°C	-	130	68	100	80	77	73	≥120	≥130
Water Content	ppm	302.11	173.63	19.64	137.29	109.65	94.61	52.36	≤500	≤500
Color	ASTM	2.7	2.2	0.7	1.7	1.5	1.3	1.2	-	-
Copper Rod Corrosion	——	1a	1a	1a	1a	1a	1a	1a	Class 1	No.3 max.

Thus, it may be possible to identify the sources of uncertainty and to reduce the amount and ratio in the system. It is calculated by Equation of n independent variables ($y_1,\ldots, y_n$) and uncertainty ratios ($z_1, \ldots, z_n$). (1) [21, 22].

$$W_R = \left[\left(\frac{\partial R}{\partial y_1} z_1\right)^2 + \left(\frac{\partial R}{\partial y_2} z_2\right)^2 + \cdots \ldots \ldots + \left(\frac{\partial R}{\partial y_n} z_n\right)^2\right]^{1/2} \quad (1)$$

Based on the above equation, the state of the uncertainty ratio equations for the braking power of the motor test setup Eq. (2). Where z_τ and z_n are the uncertainty ratios of the braking torque and engine speed [23].

$$Wp_b = \left[\left(\frac{\partial p_b}{\partial n} z_n\right)^2 + \left(\frac{\partial p_b}{\partial \tau} z_\tau\right)^2\right]^{1/2} \quad (2)$$

Below is a power calculation for D_{100} fuel.

$$P = \frac{n*L*F}{9549} (kW) \quad (3)$$

Moment is measured in Nm. Speed is measured in min^{-1}. Power is measured in watts.

n: 1000 min^{-1} ± 50

P: 7.483 HP = 7.483 / 1.36 = 5.503 kW

L: 0.35 m±0.01

F: 150.135 N ± 0.01

$$\frac{\partial P}{\partial F} = \frac{n*L}{9549} = \frac{1000*0.35}{9549} = 0.037 \quad (4)$$

$$\frac{\partial P}{\partial L} = \frac{n*F}{9549} = \frac{1000*150.135}{9549} = 15.723 \quad (5)$$

$$\frac{\partial P}{\partial n} = \frac{L*F}{9549} = \frac{0.35*150.135}{9549} = 0.006 \quad (6)$$

$$W_P = \sqrt{\begin{bmatrix} (0,037)^2 * (0,01)^2 \\ + (15,723)^2 * (0,01)^2 \\ + (0,006)^2 * (50)^2 \end{bmatrix}} \quad (7)$$

$$W_p = 0.317$$

$$\%W_p = \frac{W_p}{P} * 100 = \frac{0.317}{5.503} * 100 = 5.75\% \quad (8)$$

The results of uncertainty analysis are given in table 2 for all measurements.

Error Bars give a general idea of how accurate measurement helps to show estimated error or uncertainty. This is done using the notation, the original chart, and the markings drawn on the data points. Error bars are plotted with uncertainty analysis in experiments.

4. Energy Analysis

Combustion process in internal combustion engines; It provides the movement of piston

Table 2. Results of uncertainty analysis

Speed, min^{-1}	Power, %	D_{100}		$B_{50}D_{50}$		$B_{20}D_{80}$		$B_{10}D_{90}$		B_5D_{95}	
		T, %	SFC %	T, %	SFC %	T, %	SFC %	T, %	SFC %	T, %	SFC %
1000	5.759	0.600	0.106	0.606	0.106	0.604	0.106	0.607	0.109	0.575	0.100
1100	5.369	0.624	0.111	0.626	0.112	0.625	0.110	0.627	0.114	0.623	0.113
1200	5.052	0.636	0.116	0.635	0.114	0.627	0.115	0.638	0.118	0.639	0.117
1300	4.791	0.651	0.120	0.656	0.120	0.664	0.125	0.661	0.128	0.662	0.126
1400	4.574	0.676	0.137	0.685	0.131	0.679	0.133	0.684	0.139	0.678	0.131
1500	4.390	0.707	0.154	0.698	0.140	0.699	0.141	0.692	0.150	0.698	0.139
1600	4.234	0.711	0.131	0.725	0.121	0.716	0.122	0.725	0.129	0.721	0.121
1700	4.100	0.743	0.109	0.736	0.111	0.738	0.107	0.760	0.136	0.743	0.106
1800	3.985	0.759	0.108	0.766	0.102	0.759	0.106	0.761	0.104	0.757	0.105
1900	3.884	0.761	0.093	0.779	0.087	0.779	0.094	0.789	0.119	0.777	0.099
2000	3.796	0.804	0.091	0.799	0.088	0.798	0.096	0.806	0.090	0.805	0.090
2100	3.719	0.824	0.083	0.823	0.081	0.820	0.094	0.839	0.091	0.825	0.086
2200	3.651	0.823	0.075	0.829	0.078	0.816	0.084	0.828	0.091	0.829	0.082
2300	3.590	0.842	0.057	0.827	0.050	0.850	0.060	0.837	0.069	0.841	0.070
2400	3.536	0.882	0.037	0.882	0.033	0.891	0.039	0.864	0.044	0.883	0.042

by converting the chemical energy of the fuel into heat energy and converting the heat energy released into mechanical energy in the cylinder [24]. In internal combustion engines, not all of the fuel energy released as a result of the combustion of fuel can be converted into work [25]. Energy analysis gives an idea to calculate energy changes [26].

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (9)$$

$\dot{m}_{in}$: The inlet mass that consisting of air and fuel

$\dot{m}_{out}$: The outlet mass consisting of exhaust gases

$$\dot{E}_{fuel} = \dot{W} + \dot{Q}_{lost} \quad (10)$$

$\dot{E}_{fuel}$: The fuel energy rate

$\dot{W}$: Brake power

$\dot{Q}_{lost}$: The lost energy rate

$$\dot{E}_{fuel} = \dot{m}_{fuel}.Hu \quad (5)$$

$\dot{m}_{fuel}$: Flow rate (Mass)

Hu : Calorific value (Lower)

The reason for the low calorific value of the fuel in this process is that the water released in the vapor phase at the end of combustion has the maximum combustion temperature [22]. In the literature, the calorific value (lower) of the fuel is used in calculations.

$$W^{\cdot} = (\tau.n.\pi)/30 \quad (5)$$

5. Result and Discussion

5.1. Engine torque

The variation of torque values in the experiments performed at full load in the use of D_{100}, $B_{50}D_{50}$, $B_{20}D_{80}$, $B_{10}D_{90}$ and B_5D_{95} fuel mixtures is shown in Figure 1. Maximum torque (engine) was measured as 53.723 Nm in D_{100} fuel at 1200 min^{-1}. Comparison to D_{100} fuel, $B_{50}D_{50}$ fuel produced 3.639%, $B_{20}D_{80}$ fuel 3.421%, $B_{10}D_{90}$ fuel 1.481% and B_5D_{95} fuel 0.437% less torque.

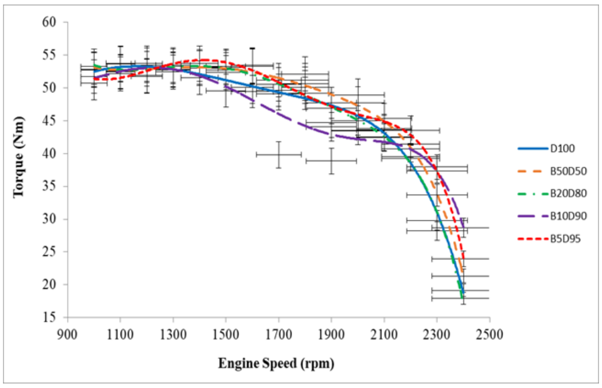


Figure 1. Torque values related to engine speed

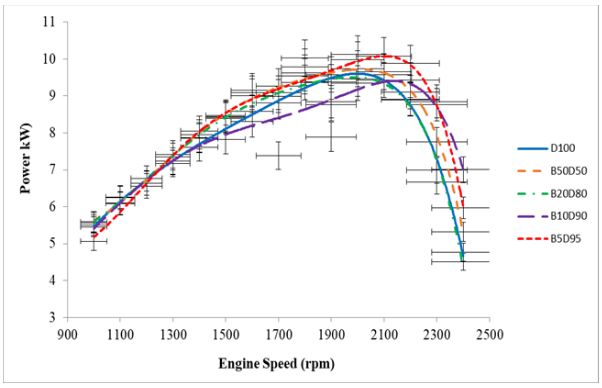


Figure 2. Power values related to engine speed

5.2. Engine power

The variation of power values in the experiments performed at full load in the use of D_{100}, $B_{50}D_{50}$, $B_{20}D_{80}$, $B_{10}D_{90}$ and B_5D_{95} fuel mixtures is shown in Figure 2. Maximum power (engine) was measured as 10.120 kW in D_{100} fuel at 2000 min^{-1}. Comparison to D_{100} fuel, $B_{50}D_{50}$ fuel produced 7.658%, $B_{20}D_{80}$ fuel 6.511%, $B_{10}D_{90}$ fuel 3.705% and B_5D_{95} fuel 1.442% less power.

5.3. Specific fuel consumption

The variation of fuel consumption (specific) values in the experiments performed at full load in the use of D_{100}, $B_{50}D_{50}$, $B_{20}D_{80}$, $B_{10}D_{90}$ and B_5D_{95} fuel mixtures is shown in Figure 3. Minimum fuel consumption (specific) was measured as 326.425 g/kWh in D100 fuel at 1500 min^{-1}. Comparison to D_{100} fuel, $B_{50}D_{50}$ fuel used 10.475%, $B_{20}D_{80}$ fuel 8.967%, $B_{10}D_{90}$ fuel 7.184% and B_5D_{95} fuel 2.309% more specific fuel consumption.

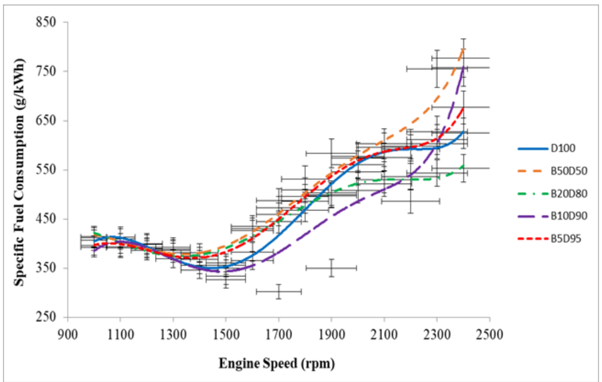
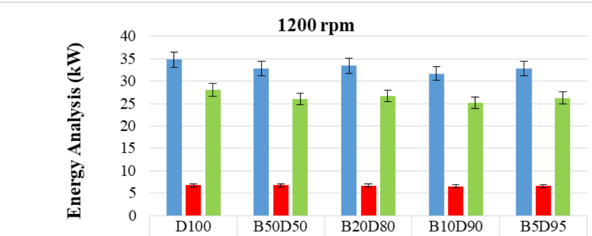
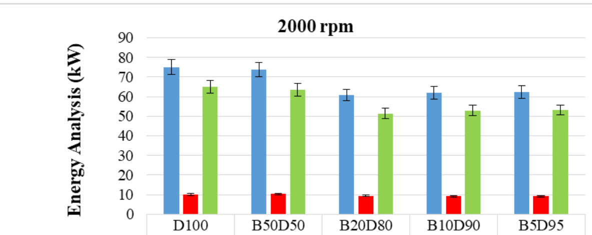


Figure 3. Specific fuel consumption values related to engine speed



	D100	B50D50	B20D80	B10D90	B5D95
Fuel Energy Rate	34.805	32.821	33.443	31.724	32.857
Brake Power	6.751	6.757	6.721	6.525	6.596
Lost Energy Rate	28.054	26.064	26.722	25.199	26.261

Figure 4. Energy analytics of fuels at a maximum torque of 1200 min^{-1}



	D100	B50D50	B20D80	B10D90	B5D95
Fuel Energy Rate	75.053	73.848	60.800	61.955	62.288
Brake Power	10.006	10.254	9.430	9.109	9.120
Lost Energy Rate	65.047	63.594	51.370	52.846	53.167

Figure 5. Energy analytics of fuels at a maximum power of 2000 min^{-1}

5.4. Energy analytics

Figure 4 and Figure 5 show the energy analysis results for maximum torque and maximum power cycles of the experiments with material fuels. For all fuels, it was determined that the fuel energy flow increased with the engine speed.

6. Conclusions

In this study, biodiesel production was conducted using Brassica rapa ssp. Oily turnip seeds from the Br-2 (Kaan variety candidate) genotype. The oily turnip obtained from the Br-2 genotype underwent transesterification and was blended with biodiesel at volumetric ratios of 50%, 20%, 10%, and 5%. This resulted in the creation of experimental fuels denoted as D_{100}, $B_{50}D_{50}$, $B_{20}D_{80}$, $B_{10}D_{90}$, and B_5D_{95}, respectively. The fuel properties were examined, and single-cylinder diesel engine performance tests, energy analyses, and uncertainty analyses were performed. The obtained data are presented graphically. In the test results, the maximum torque was measured as 53.723 Nm at 1200 min^{-1} for D_{100} fuel. Compared to D_{100} fuel, $B_{50}D_{50}$ fuel exhibited a 3.639% decrease in torque, while $B_{20}D_{80}$ fuel showed a 3.421% decrease, $B_{10}D_{90}$ fuel displayed a 1.481% decrease, and B_5D_{95} fuel demonstrated a 0.437% decrease. Similarly, the maximum power was measured as 10.120 kW at 2000 min^{-1} for D_{100} fuel. Compared to D_{100} fuel, $B_{50}D_{50}$ fuel showed a 7.658% decrease in power, while $B_{20}D_{80}$ fuel exhibited a 6.511% decrease, $B_{10}D_{90}$ fuel displayed a 3.705% decrease, and B_5D_{95} fuel demonstrated a 1.442% decrease. This trend is attributed to the lower calorific value and higher viscosity of biodiesel, as indicated in Table 1. The decrease in torque and power correlates with the proportion of biodiesel in the blend fuels. The minimum specific fuel consumption in D_{100} fuel at 1500 min^{-1} was measured as 326.425 g/kWh. Compared to D_{100} fuel, $B_{50}D_{50}$ fuel showed a 10.475% increase in specific fuel consumption, while $B_{20}D_{80}$ fuel exhibited an 8.967% increase, $B_{10}D_{90}$ fuel displayed a 7.184% increase, and B_5D_{95} fuel demonstrated a 2.309% increase. This is attributed to the lower heating value of biodiesel compared to

D_{100} fuel, as shown in Table 1. The increase in specific fuel consumption is consistent with the ratio of biodiesel in the blended fuels. Energy analysis results are provided for the maximum torque speed of 1200 min^{-1} and the maximum power speed of 2000 min^{-1} for the experimental fuels. It was observed that as engine speed increased, fuel energy flow increased for all fuels. This is due to the independent nature of the lower calorific values of the fuels relative to engine speed, resulting in an increase in fuel flow rate with engine speed.

In conclusion, the addition of Brassica rapa ssp. biodiesel to diesel fuel at volumetric ratios of 5%, 10%, 20%, and 50% yielded negative results in terms of performance. While these test fuels can be utilized without engine modifications, they are likely to incur losses in engine performance. This study contributes to the literature on Brassica rapa biodiesel production and its application in internal combustion engines.

Credit Authorship Contribution Statement

Fatih Aydın: Formal analysis, original draft, software, supervision, conceptualization, methodology. **Hidayet Oğuz:** Software – methodology, formal analysis. **Seda Şahin:** Software – methodology, formal analysis. **Hüseyin Öğüt:** Software – methodology, formal analysis. **Fatma Kayaçetin:** Software – methodology, formal analysis.

Authors' Conflicts of Interest

There are no financial interests or personal relationships that may have affected the work in this article.

Statement of Industrial Relevance

With this study, It examines the viability of Brassica rapa ssp. oil turnip seeds as a potential alternative oil source for biodiesel production, emphasizing the significance of this plant within the bioenergy sector.

Data availability statement

Authors do not have permission to share data.

Statement of Novelty

The novelty of this study is that Through the evaluation of engine performance, it investigates the energy efficiency and environmental ramifications of biodiesel-diesel fuel blends. By employing methods such as energy analysis and uncertainty analysis, it provides a more comprehensive assessment of the energy balance and efficiency of biodiesel-diesel mixtures.

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