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ARTICLE

Engine Performance Using Blended Fuels of Biodiesel and Eco Diesel

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ABSTRACT

Diesel engines is an internal combustion engine with high thermal efficiency, which also uses biodiesel fuel, an environmentally friendly, non-toxic, and low sulfur content. Biodiesel has been around for a long time due to its similar characteristics to diesel fuels which has limited availability. However, several disadvantages are associated with biodiesel, such as poor volatility and high viscosity, which reduces engine performance. Therefore, this study was carried out to improve the diesel engine performance by mixing biodiesel with ecodiesel (ED), an additive produced from natural ingredients that is dissolvable in biodiesel. The biodiesel fuel properties used are density 860 kg/m^3, dynamic viscosity 4.50E-06 m^2/s, cetane number 45, and flashpoint 52°C. The results showed that biodiesel-ED mixture could improve engine performance and the optimum performance was at a speed of 3000 rpm on 43.30 (kW), 124.93 (N.m) of the engine torque, and 2.45E^{-5} (kg/kW.s) of the specific fuel consumption. According to paired sample *t*-test, the difference in the engine performance is only experienced in the torque, which has a significant increase in the composition of the biodiesel+ED by 0.07 gr mixture.

KEYWORDS

Car; vehicle; experiment; combustion; ED; renewable energy

Nomenclature

BMEP	brake means effective pressure
BP	brake power
BSFC	brake-specific fuel consumption
BTE	brake thermal efficiency
CI	compression ignition
CO	carbon monoxide
DEE	diethyl ether
DI	decision intelligence
ED	eco diesel
GVL	γ-valero lactone

HC	hydrocarbons
MORF-1	*Monoraphidium contortum*
SFC	specific fuel consumption

Symbols

P_r	road load power
C_R	coefficient of rolling resistance
M_v	mass of vehicle (kg)
ρ_a	ambient air density (1.184 kg/m^3 at 25°C)
C_D	drag coefficients
A_v	frontal area of vehicle (m^2)
S_v	vehicle speed (km/h)
T	engine torque (kg.m^2/s^2)
N	crankshaft rotational speed (rpm)
sfc	specific fuel consumption (kg/kW.s)
$\dot{m}_f$	fuel mass rate (kg/s)
$\dot{W}$	engine power (kW)
W_R	relative uncertainty
DS	deviation standard
e	exponential number
t	calculated value
n	number of data
x_i	sample mean
x	data value

1 Introduction

Diesel engines are widely used in various sectors, such as transportation, industry, and agriculture because they are internal combustion engines with high thermal efficiency [1,2]. The diesel engine production all over the world is very significant [3]. The diesel fuel is used, the availability is limited [4–7]. However, the diesel engine can also use biodiesel, a fuel with environmentally friendly, non-toxic, and low sulfur characteristics [8–11]. The use of biodiesel also has been around for a long time due to its similar characteristics with diesel fuels [12]. When biodiesel is used in the diesel engine, it does not need significant modifications [13]. Another advantage, biodiesel is an abundant renewable energy source with progressive growth in production and demand [14].

However, biodiesel has several disadvantages, such as poor volatility and high viscosity that reduce the engine's performance [15,16]. Furthermore, Biodiesel from vegetable oils has energy content close to petro-diesel and is regarded as inexhaustible because of its renewable energy source [17,18]. Abdollahi et al. [19] examined the effects of nano-emulsion biodiesel on engine efficiency, as well as the gas emission and combustion parameters of a single-cylinder air-cooled diesel engine. The results showed that the power and torque using nano-emulsion fuel improved by approximately 4.84% and 4.65%, respectively, compared to standard emulsion [19]. With the increase in load, nano fuel blends also show lower HC emission than diesel [20].

There are various disadvantages associated with biodiesel, therefore a lot of research tries to make its improvement. Xiao et al. investigated the effect of ethanol-biodiesel and n-butanol-biodiesel blends. The results showed the combustion performed is better at low engines load [21]. Wei et al. carried out research to determine the combustion performance and emission characteristics of a diesel engine powered by isobutanol/biodiesel, which was experimentally studied under different loads at the engine speed of 1800 rpm [22]. The result showed that the combustion duration decreased with a rise in the isobutanol ratio when the engine loads exceeded 0.38 MPa brake means effective pressure (BMEP).

Currently, chemical and biological catalysts are being investigated to improve engine performance, and both have their advantages and disadvantages [23]. Akos et al. stated that γ-valero lactone (GVL) is a C5-cyclic ester produced from biomass and used to provide a potentially renewable fuel for transportation and feedstock of the chemical industry [24]. Furthermore, Yordanaka et al. examined the hydroesterification process for the production of Biodiesel from *Monoraphidium contortum* (MORF-1) microalgae biomass and stated that it is a sustainable alternative to petroleum diesel fuel due to its economic, environmental, and ecological attributes [25].

To increase biodiesel performance, eco diesel (ED) is used for their mixture. Eco Diesel is a new biofuel derived from a mixture of monoglycerides (MG) and fatty acid methyl esters (FAME) which can be applied to diesel engines [26–28]. ED is a bio additive produced from natural ingredients, consisting of citronella oil, graniol, granile acetate, and citronellal acetate [29]. It is produced in solid form, making it easier for the engine to easily consume 40 liters of biodiesel. ED dissolves easily within a limited period, thereby increasing engine performance.

Previous studies related to mixing biodiesel with various substances have been carried out with the results affecting engine performance. Gaur et al. [30] found that mixing of nanoparticles and polymer waste in biodiesel affects engine performance by increasing BTE, lowering BSFC, and reducing emissions of certain pollutants such as CO, HC, NOx. Meanwhile, Sekhar et al. [31] found that mixing *Pithecellobium dulce* seed oil methyl ester increased BSFC and decreased BTE. Sharudin et al. [32] found that Palm Oil Methyl Esters (POME) addition into algae-diesel blended fuels has lower BSFC compared to diesel fuel. The CO and HC emissions were less for bauhinia variegata biodiesel test blends (0%, 25%, 50%, 75%) (except B100) but NOx emissions increased with closer engine performance when compared with diesel [33]. Furthermore, Singh et al. [34] predicted a future blend of Jatropha biodiesel B20 (20 percent biodiesel and 80 percent diesel) with the addition of a nano-catalyst will improve its thermo-physical properties and emit emissions within permissible limits. Elkelawy et al. [35] found that biodiesel from sunflower oil and soybean oil is able to refuel and operate DI engines without modifications to the engine's original fuel system because it can be mixed with pure diesel up to 70%. Moreover, Sekhar et al. [36] found that *Pithecellobium dulce* biodiesel 20% blends could be used as an alternative fuel for CI engines with no modifications in engine design. Reang et al. [37] found that blending D75B20RW5 with biodiesel shows 8% higher brake thermal efficiency and 3.33% lower BSFC compared to diesel. Whereas Dey et al. [38] found that the D85B10E5 was the most optimal mix at 100% engine loading performance. Based on the gray-fuzzy approach with the Taguchi method, the most optimum engine parameter is found in the D85B10E5 mixture at 100% [39]. While Reang et al. [40] using the Taguchi-Fuzzy optimization method found that BD10DEE10 has maximum brake thermal efficiency (BTHE) of 4.48% higher than that of diesel. Studies on biodiesel-ethanol diesel-palm mixtures also show that they have an effect on the performance of BSEC emissions, nitrogen oxides (NO_x), unburned hydrocarbons (UHC), and carbon dioxide (CO_2) [41].

Mixing biodiesel with other substances and mixing ED with other substances have an effect on the performance of diesel engines, but it is not yet known how they will affect the performance of mixing biodiesel and ED. Therefore, this study aims to examine the mixture of biodiesel and ED to reduce some of the disadvantages of fuel properties and increase engine performance. Furthermore, it also aims to determine the influence of ED on engine performances.

2 Materials and Methods

The fuel used in this study is biodiesel, with the properties shown in Table 1. For every 1 liter of biodiesel, three variations of 0.03, 0.04, and 0.07 (gr. ED) are added, respectively.

Table 1: Biodiesel fuel properties

Fuel parameters	Specification
Density (kg/m^3)	860
Dynamic viscosity (m^2/s)	4.50E-06
Cetane number	45
Flashpoint °C	52
Water content kg/kg	5.00E-07

2.1 Experimental Setup

Experiments were carried in a 2L Toyota diesel engine unit car, as shown in Table 2. Furthermore, Table 3 shows the dyno-meter used to examine the engine performance and the characteristics of the biodiesel fuel.

Table 2: 2L engine specification

Engine type	Four strokes four cylinders
Engine cylinder volume (m^3)	2.40E-03
Stroke (m)	0.09
Bore (m)	0.09
Displacement (m^3)	2.45E-06
Compression ratio	22.3
Max. power (kW)	64.13
Max. torque (N.m)/2400 rpm	165
Car mass (kg)	1250
Vehicle frontal area (m^2)	2.96

Table 3: The dyno-meter specification

Component	Dimension
Name/type	DynoJet/224x
Max. power kW	1491
Max. torque N.m	276
Max. speed kph	322

The initial test of ED on engine performance used pure biodiesel, while subsequent tests three variations of mixtures. The engine diesel unit uses a rear-wheel-drive which is connected directly to the dyno-meter roller at various engine speeds, as shown in Fig. 1. Power measurement is done by assuming the vehicle is in a running position at a steady speed (road load power). The aero dynamic drag frictions that occur on the surface in contact between the wheel and the roller dyno meter [42], so that the road load power is determined by an empirical approach in the Eq. (1):

$$P_r = 2.73C_R M_v g + \frac{1}{2}\rho_a 0.0126 C_D A_v S_v^2) S_v 10^{-3} \tag{1}$$

where C_R is the coefficient of rolling resistance ($0.012 < C_R < 0.015$)[3], Mv is the mass of vehicle (for passenger load of 68 kg, g is the acceleration due to gravity, ρ_a is the ambient air density (1.184 kg/m^3 at 25°C) C_D, car drag coefficients ($0.3 < C_R \leq 0.5$)[3], A_v is the frontal area of vehicle (m^2) and S_v is vehicle speed (km/h). Thus, the engine torque becomes the Eq. (2).

$$T = \frac{P_r}{2\pi N} \tag{2}$$

T is the engine torque and N is the crankshaft rotational speed.

Meanwhile, the specific fuel consumption is calculated using Eq. (1) and measured directly during the test by placing the fuel in a measuring cup and recorded during the testing process.

$$sfc = \frac{\dot{m}_f}{\dot{W}} \tag{3}$$

SFC is a specific fuel consumption (kg/kW. s), $\dot{m}_f$ is fuel mass rate (kg/s), $\dot{W}$ engine power (kW). Calculation of fuel consumption is carried out directly when the engine is operated at engine speed.

To prove that the addition of ED has an effect on engine performance, statistical tests are carried out using the normality test in Eq. (3) and the paired sample test in Eqs. (4)–(6). Both of these tests are based on the 0.95 confidence level, therefore, in making decisions in the normality test, if the significance value is >0.05, then the hypothesis is accepted, if the significance value is <0.05, the hypothesis is rejected. On the other hand, in the paired sample t-test, if sig. (2-tailed) <0.05, the hypothesis is accepted, and if sig. (2-tailed) >0.05, the hypothesis is rejected [43].

$$f(x) = \frac{1}{DS\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\tau}\right)} \tag{4}$$

$$t = \frac{\overline{D}}{\frac{DS}{\sqrt{n}}} \tag{5}$$

$$DS = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - x)^{-2} \tag{6}$$

where DS as deviation standard e as an exponential number, t as calculated value n as the number of data.

Machine operation and physical parameters cause some uncertainty in the experimental results [44] so that uncertainty analysis is needed [45]. Uncertainty error analysis is a type of characteristic analysis which is analogous to the deviation of the experimental output response that can be solved effectively [46]. Therefore, uncertainty analysis can be a useful approach for communicating the researcher's level of confidence in the results and their main conclusions [47]. In this study, the uncertainty of the dependent variable was calculated using the errors involved in measuring independent parameters using Eq. (7) [48].

$$W_R = \left(\left[\frac{\partial R}{\partial x_1} w_1 \right]^2 + \left[\frac{\partial R}{\partial x_2} w_2 \right]^2 + \cdots + \left[\frac{\partial R}{\partial x_n} w_n \right]^2 \right)^{\frac{1}{2}} \tag{7}$$

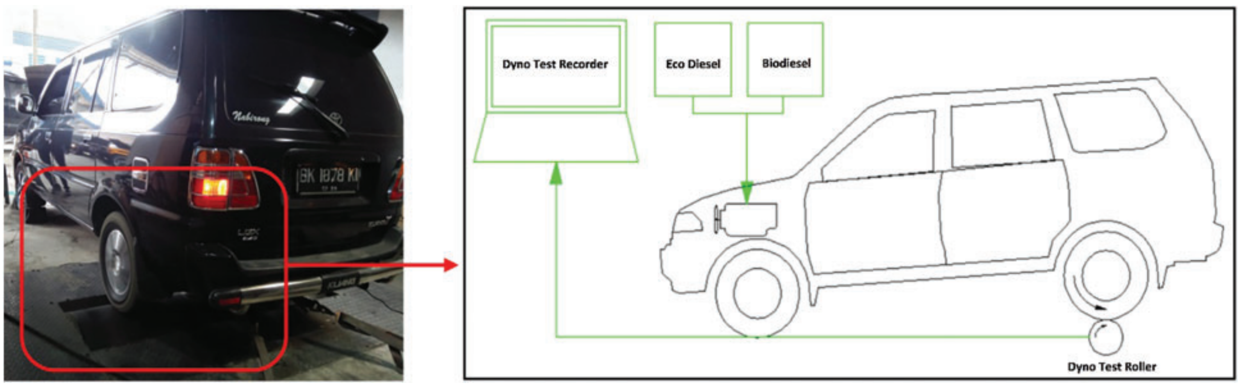

Figure 1: Experimental set up diesel engine performance procedures

3 Result and Discussion

The engine performances are presented in four rotation speed variations, as shown in Figs. 2 and 3. These figures show that ED affects engine power and torque at each rotation speeds variation. The increased power in each composition is 1.1–2.6 (kW/ED 0.03 gr), 1.6–3.6 (kW/ED 0.04 gr) and 2.1–5.2 (kW/ED 0.07 gr). Furthermore, torque increases in the first, second, and last mixing by 1.5–10 N.m, 1.9–21.6 N.m, and 3.72–16.43 N.m, respectively. The optimum engine performances for pure biodiesel and the respective mixture at 3000 rpm, are 39.7 kW/123.0 N.m, 43.3 kW/124.5 N.m, 43.3 kW/124.9 N.m and 44.3 kW/126.4 N.m. Several studies stated that the addition of natural additives to fuel increases in engine performance [49–51].

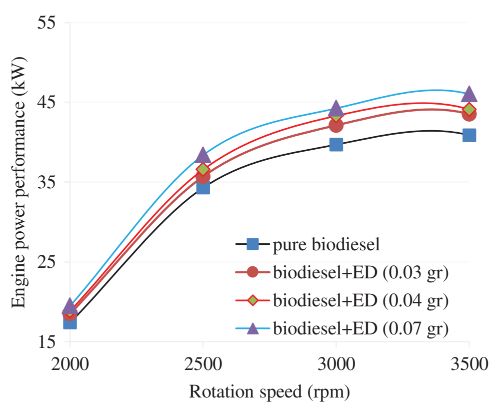

Figure 2: Engine power

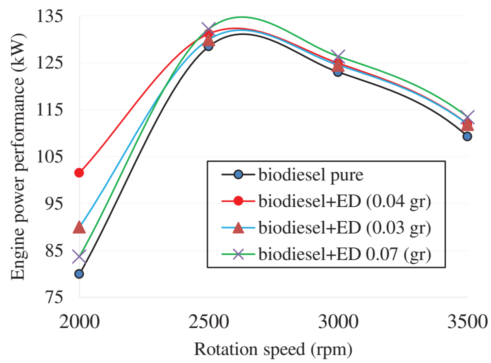

Figure 3: Engine torque

Fig. 4 is a graph of specific fuel consumption. In these three figures, the specific fuel consumption of pure diesel increases first at 2000 rpm by $5.1E^{-5}$ kg/kW.s, while ED mixed with biodiesel rises in three different variations of $3.9E^{-5}$; $3.8E^{-5}$ and $3.3E^{-5}$ (kg/kW.s), respectively. The figures show that the three variations of the ED mixture of biodiesel have an effect that causes a decrease in the specific fuel consumption at each variation of rotation speed. The most efficient BSFC at optimum engine performance generally occurs at 3000 rpm engine speed [52–55].

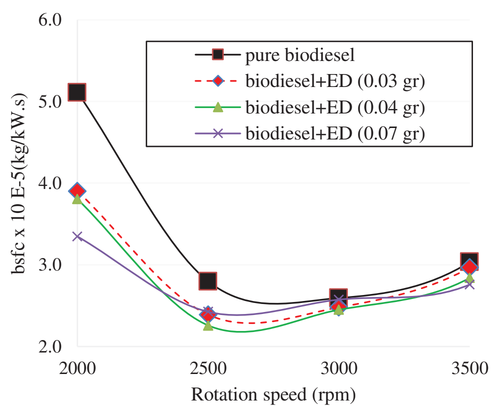

Figure 4: Break specific fuel consumption

Approximately 0.04 grams of ED in 1 liter of biodiesel when the engine performance was tested using a dyno-meter, thereby producing optimum engine performance as shown in Fig. 5. The engine power, torque and specific fuel consumption were 43.30 (kW), 124.93 (N.m) and $2.45E^{-5}$ (kg/kW.s) at 3000 rpm. The engine performances; power and torque as well as the increase in SFC efficiency as shown in pictures gb1 and gb2 are the addition of ED as an additive. This reason is supported by several studies reported [56–61]. That, in general, additives have a decreasing effect on the density of biodiesel fuel and an increase in the cetane index. This is consistent with the fuel after the addition of ED, which has given the characteristic effect of biodiesel changes in this study, although the changes of fuel in this study are not significant. A decrease in biodiesel density and an increase in CN causes a shorter ignition delay time, thus having an impact on engine performance [62–66]. These results indicate that fuel density and viscosity play an important role in the fuel injection system, flame propagation, and combustion process in compression ignition engines [67].

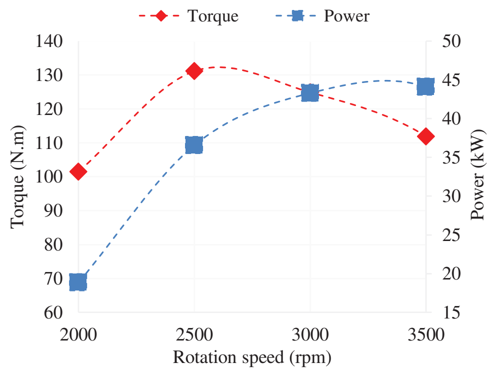

Figure 5: Optimum engine performance fueled by biodiesel ED 0.04 gr blended

The first step to determine the effect of adding ED to engine performance, is testing each data with a normality test based on Shapiro Wilk's theory, as shown in Eq. (2), where the results of these tests are shown in Table 4 and Fig. 5. The std_power as a power fueled by biodiesel without ED blend and the power_1 to power_3 and the torque_1 to torque_3 as power and torque fueled by biodiesel ED blend explained before.

Table 4: Power and torque engine tests of normality

Parameters	Shapiro-Wilk		
	Statistic	df	Sig.
Std_Power	0.872	5	0.273
Power_1	0.902	5	0.421
Power_2	0.931	5	0.602
Power_3	0.814	5	0.104
Std_Torque	0.882	5	0.319
Torque_1	0.909	5	0.462
Torque_2	0.962	5	0.820
Torque_3	0.848	5	0.189

The theory in taking decisions previously mentioned that if sig. > 0.05, then the hypothesis is accepted, therefore the engine power and torque data changes are normally distributed. This is similar to the normality test on the SFC, shown in Table 5, and Fig. 6 with a significant result above 0.05.

Table 5: SFC test of normality

Parameters	Shapiro-Wilk		
	Statistic	df	Sig.
Pure_bioiesel	0.847	5	0.185
+ED_0.03 gr	0.881	5	0.316

(Continued)

Table 5 (continued)

Parameters	Shapiro-Wilk		
	Statistic	df	Sig.
+ED_0.04 gr	0.899	5	0.406
+ED_0.07 gr	0.908	5	0.453

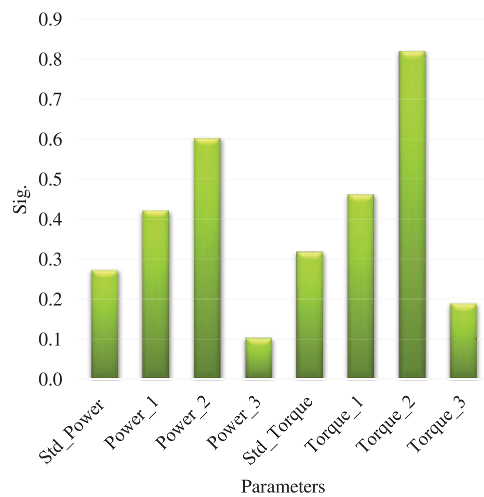

Figure 6: Power and torque engine tests of normality

After the normality test, the paired test is carried out to determine the power, torque, and specific fuel consumption variables of Eqs. (3) and (4). The results of these tests are shown in Table 6, and Fig. 7. These data illustrate an average difference between engine power and torque before using ED as a fuel additive with engine power and torque after using ED in each mixture variation. The difference in engine power and torque are 2051–4049 (kW), and 10,565–6,606 (N.m), respectively.

Table 6: Power, torque, eg. of paired differences of lower upper

Parameters		Paired differences	
		95% confidence interval of the difference	
		Lower	Upper
Pair 1	Std_P. eg. - P. eg. _1	−1.240	0.811
Pair 2	Std_ P. eg. - P. eg. _2	−5.865	2.184
Pair 3	Std_ P. eg. - P. eg. _3	−3.293	0.756
Pair 4	Std_Torq. – Torq._1	−10.208	0.356
Pair 5	Std_ Torq. – Torq._2	−17.843	2.863
Pair 6	Std_ Torq. – Torq._3	−8.201	−1.595

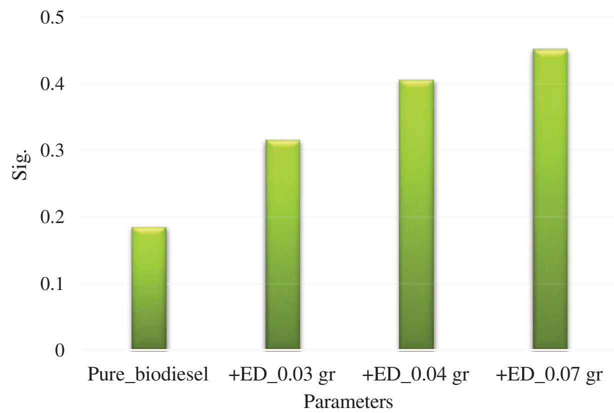

Figure 7: SFC tests of normality

Table 7 and Fig. 8 show that each ED mixture of biodiesel tends to differ in the specific fuel consumption between 1.14–1.68 (E^{-5} kW/s). This indicates that there is a saving effect in the use of fuel, even in small amounts.

Table 7: SFC of paired differences of lower upper

Parameters		95% confidence interval of the difference (E^{-5} kW/s)	
		Lower	Upper
Pair 1	Pure_Bioesel +ED_0.03 gr	−0.141	1.005
Pair 2	Pure_Bioesel +ED_0.04 gr	−0.063	1.102
Pair 3	Pure_Bioesel +ED_0.07 gr	−0.223	1.463

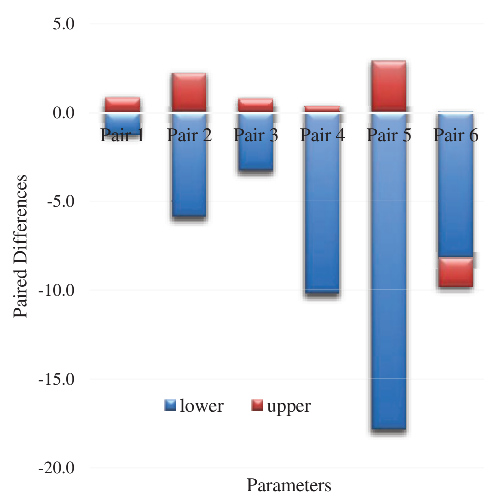

Figure 8: Differences of lower upper

The significant difference of adding ED to engine performance is determined by the paired-sample *t*-test method, with the hypothesis result smaller than the significant 2-tailed, shown in Table 9. Tables 8, as well as Figs. 9 and 10 are the results of paired sample *t*-test. These results illustrate that only the torque significance in pair 6 has a biodiesel composition rate of +ED_0.07 gr as shown in Fig. 11.

Table 8: Significance paired-samples *t*-test of power and torque engine

Parameters		Sig. (2-tailed)
Pair 1	Std_P. eg. - P. eg. _1	0.592
Pair 2	Std_ P. eg. - P. eg. _2	0.273
Pair 3	Std_ P. eg. - P. eg. _3	0.157
Pair 4	Std_Torq. – Torq._1	0.061
Pair 5	Std_ Torq. – Torq._2	0.115
Pair 6	Std_ Torq. – Torq._3	0.015

Table 9: Significance paired-samples *t*-test of SFC

Parameters		Sig. (2-tailed)
Pair 1	Pure_Bioesel - +ED_0.03 gr	0.104
Pair 2	Pure_Bioesel - +ED_0.04 gr	0.069
Pair 3	Pure_Bioesel - +ED_0.07 gr	0.111

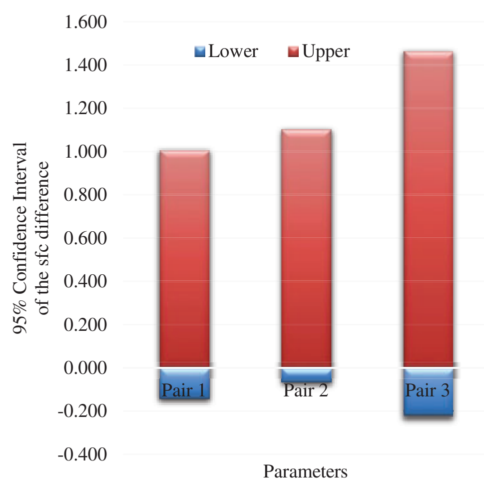

Figure 9: SFC of paired differences of lower upper

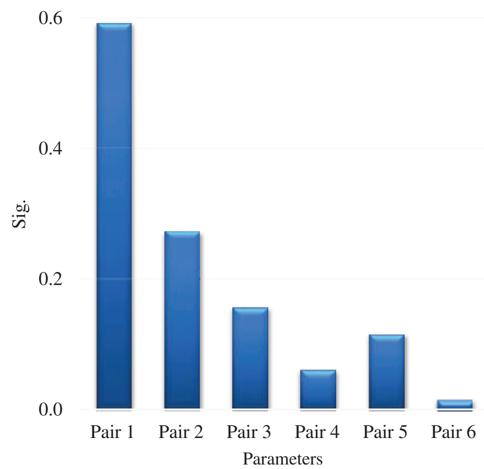

Figure 10: Significance paired-samples *t*-test of power and torque engine

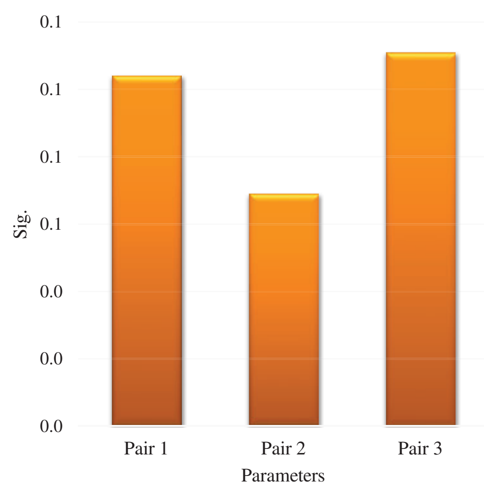

Figure 11: Significance paired-samples *t*-test of SFC

4 Conclusion

In conclusion, ED mixture in biodiesel fuel has a positive effect on improving engine performance as follows:

1. The maximum engine power fueled by pure biodiesel at 40.86 kW increased after biodiesel is mixed with ED, in percentages of 38.8%, 34.4%, and 35.5%, with a maximum engine power of 3500 rpm.
2. The maximum engine torque at 3000 rpm for pure biodiesel is 123.04 N.m with an increase in ED mixtures by 1.2%, 1.5%, 2.7%.
3. The most efficient specific fuel consumption at 2500 rpm using pure biodiesel was 2.59 E^{-5} (kg/kW.s), decreasing 4%, 6%, and 1%, respectively.

4. The optimum engine performance at 3000 rpm, fueled by a mixture of 1 litter biodiesel with ED 0.04 gr, where the engine power, torque, and specific fuel consumption values are 43.30 (kW), 124.93 (N.m), and 2.45E^{-5} (kg/kW.s), respectively.

Engine performance testing was carried out by direct measurement using a dyno-meter and the paired-sample *t*-test method. The results obtained from the dyno-meter tend to increase power, torque, and SFC before and after using the ED. However, the difference in the engine performance of the three variables is only experienced in the torque, which has a significant increase in the composition of the biodiesel+ED by 0.07 gr mixture.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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