scientific reports

OPEN

On field assessment of tractor performance and emission fueled by blends of ethanol and waste cooking oil methyl ester

Amir Shayei[1], Gholamhossein Shahgholi[1]✉, Sina Ardabili[2]✉ & Mohammad Ali Keyhandoust[1]

Farming tractors consume the most share of diesel fuels in agricultural sectors. As most engine tests are performed in engine laboratories, the study aims to examine the effect of biodiesel, diesel, and ethanol blends in actual farming conditions. Accordingly, the percentage of ethanol and biodiesel and the gear (forward speed) were considered the independent variables. The output variables were the slippage percentage, traction efficiency (TE), and emission factors. It was found that B2E7 (2% biodiesel including 7% ethanol) provided the lowest slippage percentage in comparison with control (about 15, 17 and 19% respectively for L1 (low gear 1), L2 (low gear 2) and L3 (low gear 3)). On average, increasing the gear level increased the slip percentage by about 8 and 14% for L2 and L3 compared to L1, respectively. Also, increasing forward speed (increasing gear from L1 to L3) reduced the traction efficiency. The maximum traction efficiency was obtained at B2E7, followed by B5E7, which were, on average, about 3 and 3.5% higher than the control, respectively. The optimization results indicated that the highest performance and the lowest emission were obtained using a fuel with a formulation of 0.2% ethanol and 4.1% biodiesel (B4.1E0.2) at L3.

Keywords Biofuel, Traction efficiency, Farming tractor, Diesel engine emission, Biodiesel

Abbreviations

TE	Traction efficiency
CO	Carbon monoxide
CO2	Carbon dioxide
NOx	Nitrogen oxide
KoH	Potassium hydroxide
HCl	Hydrochloric acid
B	Biodiesel
2WD	Two wheel drive
ASTM	American Society for Testing and Materials
E	Ethanol
L1	Low gear 1
L2	Low gear 2
L3	Low gear 3
ANOVA	Analysis of variance
BxEy	Fuel containing x% biodiesel and y% ethanol

The consumption of fossil fuel resources has raised concerns about access to energy resources in the coming years[1]. The agricultural machinery sector can be considered one of the largest energy consumers in the world. Internal combustion engines are frequently used in agricultural machinery applications[2]. The diesel engine is a type of internal combustion engine. Diesel engines are crucial for numerous transportation and agricultural applications due to their effectiveness, longevity, and considerable torque at low engine speeds[3]. Agricultural tractors are frequently powered by diesel engines[4]. Agricultural tractors are vehicles designed to carry out various activities, particularly soil tillage and traction labor, coupled with numerous implements[3].

[1]Department of Biosystems Engineering, Faculty of Agriculture and Natural Resource, University of Mohaghegh Ardabili, PO Box: 56199-11367, Ardabil, Iran. [2]Department of Engineering Sciences, Faculty of Advanced Technologies, University of Mohaghegh Ardabili, Ardabil, Iran. ✉email: shahgholi@uma.ac.ir; sina.faiz@uma.ac.ir

In the agricultural sector, the most share of energy consumption is targeted by tractors[5]. The contact between the tractor drive wheel and the soil transforms the engine's power into the pulling force[6]. Fuel characteristics are an essential factor affecting a tractor's performance, fuel consumption, and emission characteristics[7].

According to the pieces of literature, higher energy consumption, particularly for non-renewable energy sources like diesel, is a result of more significant usage of agricultural machinery[8,9]. In recent years, researchers have been studying biofuels that harm the environment less while meeting the demands of machines to fulfill the need for fuels and ecological awareness. In various studies in the field of combustion, efforts to find alternative fuels or optimal fuel compositions have been considered[10,11]. The development and improvement of alternative energies are essential factors in the growth of a sustainable economy, and biodiesel, with its particular conditions and characteristics, can be called one of the most important alternatives to diesel, which has attracted more attention at the moment. Renewability, non-toxicity, higher lubrication, higher flash point temperature, and biodegradability are the advantages of biodiesel compared to diesel fuel[12–14].

Several studies examined the effect of biodiesel on the performance of agricultural tractors. Sala et al. (2023) used controlled adjustment of the fuel feeding system settings and mixtures of 10, 20, and 30% biodiesel to test the behavior of a four-cylinder farm tractor diesel engine. The prepared fuel samples improved the engine efficiency[15]. Sawasaki et al. examined how an agricultural tractor performs and emits pollutants during soil tillage based on biodiesel fuel mixtures with diesel fuel. The proposed fuel mixtures successfully affected the fuel consumption, traction force, and engine emissions during the experiment[16]. Tomic et al. examined the impact of sustained usage of pure diesel and a biodiesel fuel blend on the modifications to the engine's output and exhaust gas emissions of a tractor used in routine agricultural work[17]. In the study by Shevtsov et al., the traction force was almost constant in using a rapeseed biodiesel mixture compared with pure diesel fuel. Also, biodiesel blends improved the engine emission compared with pure diesel fuel[18]. Ranganathan et al. (2021) employed biodiesel in an off-road twin-cylinder compression ignition engine. The biodiesel was formulated using the ultrasound-irradiated transesterification process. The experiments were conducted on a Mahindra-Maximo twin-cylinder tractor engine to evaluate the performance, emission, and combustion behavior. They tested different blends of 10, 15 and 20% were prepared and experimented on a Mahindra-Maximo twin cylinder tractor engine in order to analyse its performance, emission and combustion behaviour. As compared to diesel, biodiesel blends offer increased specific fuel consumption with comparable brake thermal efficiency for all the engine speeds. All blends diminished CO emissions by 16.12%, 22.58% and 29.03%, HC emission by 19.04%, 42.8% and 61.9% as well as smoke opacity by 14.28%, 28.57% and 42.85% in comparison with diesel. Therefore, biodiesel can be a cost-effective fuel and blends could be used as off-road diesel engine substitutes.

Compared to diesel, biodiesel blends increased the specific fuel consumption with comparable brake thermal efficiency using a fuel sample containing 10% of biodiesel. Increasing the biodiesel percentage reduced carbon monoxide (CO) emissions, hydrocarbon emissions, and smoke opacity and increased the nitrogen oxides (NOx) emission compared to neat diesel fuel[19]. Nuanual et al. employed two blends of diesel and biodiesel fuels containing B12 and B88 (12 and 88% of biodiesel, respectively) for assessing a mini-farming tractor's performance and emission characteristics. The results indicated that biodiesel and diesel enhanced the fuel properties of the blends, similar to those of diesel. However, the B88 combination emitted lower pollutants than B12 and neat diesel fuel[20].

Although many studies emphasize that biodiesel will lead to a cleaner environment and its unique benefits, such as promoting sustainable development and reducing greenhouse gas emissions, there is still a gap until all can use biodiesel as an ideal alternative fuel. Such perception is attributed to the increase in NOx emissions, as mentioned earlier, and the lower energy of biodiesel, which can increase fuel consumption. However, it is increasingly believed that new technologies, such as modern electronic fuel injection and various fuel additives, can overcome such deficiencies[21]. Meanwhile, alcohol additives such as ethanol, known as oxygen additives, are known as promising additives[22]. Karin et al. claimed that ethanol in biodiesel and diesel blends could reduce diesel engine smoke emissions[22]. In the study by Adrian et al. (2022), ethanol blended with diesel fuel reduced NOx and Soot emissions by about 9 and 19%, respectively[23]. Liang et al. (2022) reported that ethanol in biodiesel-diesel fuel samples improves engine efficiency[24]. The study by Zhong et al. reduced NOx and CO emissions at complete load conditions using ethanol at low portions in biodiesel-diesel fuel samples[25].

As it is clear from the studies, many studies have been done in engine laboratory conditions. So, the actual performance conditions are very different from the laboratory conditions, and the obtained results may be affected by various work factors. Therefore, some experiments performed in laboratory conditions are unreliable to generalize to actual conditions. Based on this, the need to perform fuel tests in actual performance conditions is necessary to reach a reliable result.

On the other hand, the increasing fuel price and the environmental impacts of fuel pollutants prompt us to optimize the fuel consumption of the tractors and use low-cost fuel additives. Table 1 presents a comprehensive overview of the conducted studies for analyzing the tractor performance and emission fueled by different fuel samples.

As can be seen from Table 1, the number of studies that have evaluated tractor performance in real conditions and on field condition is limited, and many studies have been conducted to evaluate tractor performance in a laboratory environment. It can also be said that many studies have used diesel fuel or a mixture of diesel fuel and biodiesel as fuel input. Among the differences between the present study and the studies conducted, one is conducting the test in real farming conditions and the other is the use of a triple fuel mixture including diesel-biodiesel-ethanol as input fuel.

One of the advantages of biodiesel is the reduction of some of the pollutants emitted from combustion compared to standard diesel fuel, which is due to the oxygen content in the structure of biodiesel. In accordance with the Paris Agreement on reducing greenhouse gas emissions, compatibility and finance, this reduces the economic cost of combustion emissions. Accordingly, replacing even a percentage of fossil fuels with biodiesel

Refs.	Testing fuel	Test condition	Performance parameters	Optimal fuel percentage	Reason	Performance	Emission
[26]	Diesel and di-ethyl ether	Laboratory, constant engine speed (1500 rpm)	Fuel consumption	DEE30	Higher cooling effect from DEE vaporization	N.A.	NOx and Soot
[27]	Diesel and Biodiesel	Laboratory, Simpson's S-217 tractor diesel engine, at full load	Acceleration and noise	P75SNB25	The oxygenated nature of the biofuel blends	Increasing the BP, Reducing BSFC	N.A.
[28]	Diesel and Biodiesel	Laboratory at different engine speeds of Kubota M1-100 S-DT 73.6 kW four-cylinder farm tractor	Brake torque, indicated power, fuel consumption (BSFC)	Waste Vegetable Oil Biodiesel	The oxygenated nature of the Biodiesel	Increasing BSFC	Increasing NOx, Reducing CO, reducing CO2 and increasing O2
[29]	Diesel	On farm- Massey Ferguson MF6499 with reversible six-furrow plough Kverneland EG 100	Fuel consumption	N.A.	N.A.	Not applied	CO2, NOx and CO
[30]	Diesel and Biodiesel	On farm	Fuel consumption and drawbar power	Diesel and B40	The oxygenated nature of the Biodiesel	Reducing emissions and increasing the performance	CO2, NOx and CO
[31]	Diesel	On farm	Traction efficiency, and fuel consumption	N.A.	Not applied	increasing the ploughing performance	CO2 and CO
[32]	Diesel and Biodiesel	Laboratory	Engine power, and Fuel consumption	50% jatropha biodiesel	The chemical structure of the fuel	Reducing emissions and increasing the performance	Smoke, CO, HC, NOx, and PM
Present study	Diesel, Biodiesel and ethanol	On farm	Traction efficiency and slip percentage	Refer to results	Refer to results	Refer to results	NOx, CO, and CO2

Table 1. An overview of the conducted studies for analyzing the tractor performance and emission. N.A.: Not available.

fuel can be an effective measure in line with sustainable energy production policies. One of the objectives and results of the research is to find the optimal conditions for fuel performance in terms of energy production and reduction of the tractor's engine emissions in real farm conditions. Accordingly, different load and fuel type scenarios should be examined so that the optimal conditions can be discussed with strong arguments .The main aim of the study is to examine the effect of biodiesel, diesel, and ethanol blends on an agricultural tractor's performance (traction efficiency (TE) and slip percentage) and emission characteristics in actual farming conditions according to the procedure presented in the study by Moinfar et al. (2020)[5].

Based on our knowledge, this article is considered one of the important subjects on using an oxygenated alcohol additive in biodiesel-diesel fuel blends for use in tractors in actual agricultural working conditions. The steps we are looking for in this study:

- Investigating the performance of the tractor diesel engine in actual working conditions.
- Evaluate the diesel engine emissions.
- Investigating the number of slip changes in the use of fuel samples.
- Optimizing a suitable fuel formulation to increase farm tractor performance and reduce emissions.

Methodology
Fuel sample preparation
Biodiesel was prepared from edible waste cooking oil (WCO) by transesterification method. Because WCO is the most accessible, moderate, and cheapest source of production for biodiesel production, according to the studies conducted. The transesterification method is considered one of the most appropriate and widely used biodiesel production methods. Methanol was used as the required alcohol for the transesterification reaction with a molar ratio of 6:1. Equivalent to 1% WCO weight, the catalyst (Potassium hydroxide (KoH)) was added to the alcohol. This condition was selected according to the optimal condition obtained from the study by Najafi et al.[33,34]. For complete dissolution of the catalyst, the temperature was increased to near the boiling point of alcohol. In this case, potassium methoxide is prepared for the transesterification process.

At this stage, a potassium methoxide solution was added to the waste oil, and the process temperature was kept near the boiling temperature of alcohol (approximately 65 °C). Since the mixture of two substances is in a suspended state, therefore, to mix and carry out the reaction, the mixture is uniformly stirred for 90 min with an intensity of approximately 900 rpm so that the distribution of alcohol and catalyst was uniform in all parts of the oil and the transesterification reaction completed.

The obtained mixture quickly changes to dark in a short period and then turns pale red. The transesterification reaction progresses up to 98%, and if the mixture is not stirred uniformly, the combination may become waxy. After completing the response, the container containing the reacting materials is kept completely still for 8 h at ambient temperature so that the mixture temperature drops in ambient temperature (around 25 °C). Hydrochloric acid (HCl) is used to neutralize the raw biodiesel produced. After 12 h, the separated phases are separated from each other. On the upper stage of impure biodiesel, the middle step is related to glycerin, which is suspended particles, and the lower phase is sodium chloride sediment.

The produced biodiesel still contains some impurities and wax compounds, so filtering is used to remove these substances. After this step, the obtained ester has high transparency. Purifying ester with filter paper removes many suspended particles and large impurities, but it must be washed with distilled water to remove glycerin, alcohol, and other compounds. Ester is washed with hot water at a temperature of 60 °C. The volume of water used equals the importance of biodiesel in the container. It should be noted that water should be slowly added to raw biodiesel from the top. After washing, the formed emulsion is left alone for two days at ambient temperature. After two days, three distinct phases are formed inside the washing container: biodiesel, which is lighter than other phases in the upper part; soapy substances that form a white sponge in the middle of the container; and the remaining water and salt solution settles in the bottom of the container in lemon color. The longer the phase separation time, the better the quality of the final ester.

After the preparation of biodiesel, the test fuel sample was prepared in the presence of biodiesel, diesel fuel, and ethanol in different percentages, according to Table 1. Given the abundance and low price of diesel in Iran, the relatively high cost of biodiesel production, and the importance of reducing environmental pollution from diesel engine emissions in Iran, according to the Paris Agreement, it was decided to test and examine low percentages (less than 10%) so that in addition to reducing engine pollution, the cost of fuel production would be economical. Due to the biphasicization of ethanol and blended biodiesel fuels, a mixture of 1:2 Span 80 and Tween 80 surfactants (Merck, Germany) was added to make fuel blends. The emulsion fuel samples were mixed together for 15 min at room temperature using a Polytron® homogenizer from Switzerland. After 45 days, the stability of the emulsion fuels made with different amounts of biodiesel and ethanol was checked. The fuel samples were visually inspected during the experiment, and no biphasicization was observed in the biodiesel and ethanol blends. In this study, no control samples without surfactants were tested, and the stability evaluation was qualitative (visual observation over 45 days); therefore, quantitative analysis and comparison with non-surfactant controls are suggested for future work. Table 2 also presents the thermal-physical properties of fuel samples under ASTM standards.

According to Table 1, increasing the biodiesel and ethanol portions reduces the calorific value and viscosity but relatively improves the density, flash point, cloud point, and Cetane number. The next step is to present the experimental procedure.

Experimental procedure

Field trials were conducted at the University of Mohaghegh Ardabili's research farm (latitude: 38.2, longitude: 48.31, and height above sea level: 1376 m). The topsoil layer should be loose to compare the traction performance of tractors in various settings. Consequently, the area was plowed by a tandem disc harrow at a depth of 10 cm before conducting the experiments. Table 3 presents the soil characteristics which have been measured in 30 random points[5].

As a result, tests were undertaken to determine how different fuel samples (including mixtures of diesel, biodiesel, and ethanol) affected the tractor's traction efficiency at three different gear levels (low gear 1 (L1), low gear 2 (L2), and low gear 3 (L3)) at a constant engine speed of 2000 rpm. The drive wheel slippage measured tractor rolling resistance, fuel consumption, and engine emissions. Finally, slippage and rolling resistance were measured to compute the tractor's traction efficiency (TE). TE measures a tractor's engine-to-ground power transfer. It is the ratio of the tractive effort (wheel force) to the drawbar pull (load force). TE and slippage are improved when the tractor can apply maximum power to the ground. In another word, when tractor is working on farm, TE and slippage are two frequently used factors for analyzing the tractor performance[29,35].

A two-wheel drive (2WD) Massey Ferguson 285 tractor was used for the experiments. Considering the size of the farmlands in Iran, the MF285 tractor is the most widely used tractor in Iran, meaning it is considered an all-rounder for farmers. Table 4 provides the details of the tractor above. The forward speed may be altered

Order	Symbol	Diesel	Biodiesel	Ethanol	Calorific value	Viscosity @ 40 °C	Density @ 15 °C	Flash point	Cloud point	Cetan number
Standard code					ASTM D240	ASTM D445	ASTM 6751-02	ASTM D93	ASTM D2500	ASTM D613
1	DIESEL	100%	0.00%	0.00%	39.570	4.790	0.839	110.000	− 7.000	57.330
2	B2E0	98%	2.00%	0.00%	39.519	4.756	0.840	110.700	− 6.920	57.463
3	B2E5	98%	1.90%	0.10%	39.505	4.754	0.840	110.569	− 6.942	57.407
4	B2E2	98%	1.96%	0.04%	39.513	4.755	0.840	110.648	− 6.929	57.441
5	B2E7	98%	1.86%	0.14%	39.500	4.753	0.840	110.517	− 6.951	57.385
6	B2E10	98%	1.80%	0.20%	39.492	4.752	0.840	110.438	− 6.964	57.351
7	B5E0	95%	5.00%	0.00%	39.442	4.705	0.842	111.750	− 6.800	57.664
8	B5E2	95%	4.90%	0.10%	39.428	4.703	0.842	111.619	− 6.822	57.608
9	B7E0	93%	7.00%	0.00%	39.390	4.671	0.844	112.450	− 6.720	57.797
10	B5E5	95%	4.75%	0.25%	39.408	4.700	0.842	111.423	− 6.855	57.524
11	B5E7	95%	4.65%	0.35%	39.395	4.698	0.842	111.292	− 6.877	57.468
12	B5E10	95%	4.50%	0.50%	39.375	4.695	0.842	111.095	− 6.910	57.384
13	B7E2	93%	6.86%	0.14%	39.371	4.668	0.843	112.267	− 6.751	57.719
14	B7E5	93%	6.65%	0.35%	39.344	4.664	0.843	111.992	− 6.797	57.601
15	B7E7	93%	6.51%	0.49%	39.325	4.661	0.843	111.808	− 6.828	57.523
16	B7E10	93%	6.30%	0.70%	39.297	4.657	0.843	111.533	− 6.874	57.405

Table 2. The prepared fuel samples. B: biofuel E: Ethanol.

Property	Value
Plastic limit	27.89
Organic matter (g/100 g)	0.25
Liquid limit	40.62
Field capacity based on dry weight (%)	11.43
Plasticity index	13.56
Dry bulk density (g/cm^3)	1.42
Moisture content based on dry weight (%)	10.2

Table 3. The soil characteristics.

Specification	Unit	Value
Engine: Four-stroke, direct injection, water-cooling diesel		
Max. Engine power	KW	56
Injection timing	Degree	16–32 of BTDC
Displacement volume	L	5.2
Bore/Stroke	mm	114 × 127
Compression	–	17.5:1
Rated engine speed	RPM	2000
Static weight	kg	3470
Wheelbase	cm^2	225
Front tire	in	7.50–16
Rear tire	in	16.9–38

Table 4. The specification of testing tractor and engine.

by shifting the tractor gears (L1, L2, and L3) while maintaining a constant engine speed of 2000 rpm. The engine speed is set at a constant 2000 rpm by using the manual throttle control which is available in tractor. The maximum torque and most minor fuel consumption correlate with this engine speed.

An inductive proximity sensor (pr12-2dn produced by Autonics) mounted parallel to the outside edge of a sprocket that was fixed inside the tractor's rear wheel was used to measure the vehicle's wheel speed. The pulse meter's digital displayer (MP5W-44 produced by Autonics, a 5-Digit, 13 Modes, 5 NPN Outputs + Transmission output (DC4-20 MA), and 100–240 VAC), attached to a magnetic sensor, displays the wheel rotation number. The employed proximity sensor has a response frequency of 1.5 kHz, maximum current consumption of 10 mA, and a maximum residual voltage of 1.5 v. The precision of resolution of the pulse meter is 1 rpm with an accuracy of ± 1. The slip percentage was calculated using Eq. 1[36]:

$$S\,(\%) = \left(1 - \frac{v_1}{v_2}\right) \tag{1}$$

v_1 refers to the actual velocity (m. s^{-1}) value which is calculated by measuring the time required for passing 100 m. v_2 refers to the theoretical velocity, which was calculated by multiplying the rear wheel's perimeter and the tire revolutions' number.

We employed the technique presented in the study by Russini et al. (2018)[37] for calculating the pulling power. Accordingly, the Load cell (Alfa, 10T), with a capacity of 100kN and accurately measured with an accuracy of 0.01kN, was used to measure the traction force. By choosing a gear that allowed to travel at a lower speed while the differential lock was active, the tractor dragged the braking tractor with more force and mass relative to the first tractor while carrying a constant load. One hundred meters traveled in each segment without slipping the braking tractor's drive wheel. The rolling resistance at each section was calculated by pulling the test tractor using the brakes and the mean value of three observations. Values were determined by reading the load cell, which had been relocated in front of the test tractor.

Equation 2 was used to determine the tractor's traction efficiency after obtaining pulling force, rolling resistance, and drive wheel slip data.

$$\text{Traction efficiency} = \frac{P}{P+R}(1-S) \tag{2}$$

P refers to the pulling force, R refers to the rolling resistance, and S refers to the slip value. An experiment using a randomized block experimental design was considered for statistical analysis, with each treatment consisting of three repetitions. The analysis of variance (ANOVA) was then performed on the response variables (traction efficiency, slip percentage, and emission characteristics).

Parameter	Accuracy	Resolution	Parameter	Uncertainty	Percentage uncertainty (%)
Engine speed	± 1	1 rpm	Fuel flow rate	0.31 (g/h)	4.20
CO_2	± 1	0.1%	Pulling force	0.01 (N)	0.01
NO_x	± 1	1 ppm	Rolling resistance	0.01 (N)	0.01
CO	± 1	1 ppm	Traction efficiency	–	0.014

Table 5. Accuracies of measuring tools.

Source	df	Mean square				
		Slip (%)	TE (%)	CO2 (%)	CO (ppm)	NOX (ppm)
B	2	16.84**	10.16**	0.000002838^{ns}	6678.109*	2496.28**
E	2	3.16*	4.88**	4.59E-005**	37992.01**	1538.53**
Gear	2	72.713**	232.96**	0.00004278**	465.13^{ns}	2091.52**
B*E	4	14.85*	1.27^{ns}	0.00002639**	1723.72*	71.66^{ns}
B*Gear	4	0.33^{ns}	2.46*	1.173E-08^{ns}	0.1610^{ns}	133.69^{ns}
E*Gear	4	1.76^{ns}	0.22^{ns}	3.29123E-07^{ns}	361.99^{ns}	321.86^{ns}
B*E*Gear	8	0.3^{ns}	0.14^{ns}	0.000003179^{ns}	272.05^{ns}	193.84^{ns}
Error	52	3.24	0.45	5.03E-06	1023.31	105.23
Total	158					

Table 6. Results of ANOVA. **Significant at 1% level; *Significant at 5% level; ns: not-significant. B: Biodiesel; E: Ethanol.

Exhaust gas analyzing

The Seitron CHEMIST 500 Combustion and Flue Gas Analyser were used to measure the emission of exhaust gases, including CO, CO2, and NOx.

Table 5 indicates the measurement uncertainty and accuracy of the instruments employed in this experiment.

Optimization

Optimize with the Design Expert software's standard response level method to achieve a fuel formulation that can create maximum traction and minimum emissions. Based on this, independent variables, including biodiesel percentage, bioethanol percentage, and forward speed, and dependent variables, including slip percentage, traction efficiency (TE), and emissions of pollutants (carbon monoxide, carbon dioxide, sulfur dioxide, and nitrogen oxides), were determined. These parameters were selected based on the importance and priority of parameters. In the subset of the farming tractor performance, measuring the TE and slip percentage as the two most essential parameters for working the tractors on the farm were accessible. Also, the gas analyzer only could measure the CO2, CO, and NOx as actual combustion products. In real-time tractor working, the driver changes the gear level to set the tractor's forward speed variables. Accordingly, we had a fuel combination and tractor forward speed (with changing the gear level) as the independent variables and performance and emission characteristics as the dependent variables.

This method can map the process of changes by creating a linear or non-linear relationship between the dependent and independent variables and achieve an optimal level of responses based on examining the mutual effects of the parameters. This method can even extract the individual impacts of dependent and independent variables, which provides the researcher with an overview of the system's behavior.

Results and discussion

The purpose of preparing this section is to categorize and present the results of examining the effect of different fuel combinations from diesel, biodiesel, and ethanol, as well as forward speed (resulting from changes in gears L1, L2, and L3) on the performance parameters and the emission indicators of an agricultural tractor in the context of actual performance. The first step is to present the variance analysis results in the context of the ANOVA technique (Table 6). Table 6 shows the Individual and mutual effects of independent variables (including biodiesel percentage, ethanol percentage, and type of forwarding gear) on independent parameters, including slip (%), traction efficiency (%), carbon dioxide emission percentage (%), carbon monoxide (ppm), sulfur dioxide (ppm), and nitrogen oxides (ppm). To ensure the accuracy of the results, the percentage uncertainty of each of the measured variables was calculated based on the accuracy of the instruments (Table 5), and the results were within the appropriate uncertainty range.

As is clear from Table 5, only the individual effect of gear variation is not significant on the emission of CO. This trend can be due to the engine speed (2000 rpm). According to the catalog of the MF285, 2000 rpm is the effective engine speed, and based on the study by Hajlari et al.[38] and Karimi et al.[39], when a diesel engine works at the effective engine speed, the variety of engine emissions against load changes on the engine was smooth. The interval of changes in emissions was minimal. In the case of mutual effects, the interactive effect of biodiesel and ethanol was significant at a slip percentage (at the 5% level), CO2 emission (t at 1% level), and CO emission (at the 5% level). The interactive effect of biodiesel and gear significantly improved traction efficiency (at a 5% level). The mutual impact on the dependent variables is not-significant.

The mutual effect of fuel combinations and gear level on the slip percentage

Figure 1 presents the mutual effect of different fuel combinations from diesel, biodiesel, and ethanol blends and the gear level on the slip percentage. According to Fig. 3, increasing the gear level increases the slip percentage. Because expanding the gear level increases the moving speed, leading to an increase in slip percentage. Also, increasing the gear ratio reduces wheel torque, decreasing tractive effort and increasing slip percentage. This trend also was reported by Mamkagh et al. (2009)[40], Tayel et al. (2015)[41], and Mamkagh (2019)[42].

By considering the diesel fuel as the control fuel, B2E7 provided the lowest slip percentage compared to the control (15, 17, and 19%, respectively, for L1, L2, and L3), by reducing the gear from L3 to L2 and L1, the differences in slip percentage variations increase. Such that, at L2 (in comparison with L3 and control), a noticeable reduction of slip percentage has happened for B2E10, B5E2, and B5E7 (5, 6, and 5.3%, respectively), while this reduction did not occur for L3. Also, in L1, there was a reduction in the slip percentage for B2E10, B5E2, B5E7, B7E5, and B7E7 compared with control (2, 13.5, 6.2, 1.5, and 1.3%, respectively).

Different fuel types have varying effects on the traction between the tires and the ground. Traction is essential for maintaining control and preventing slippage. The slip ratio can be influenced by how well the tires grip the ground, which in turn can be affected by the properties of the fuel. Also, the combustion characteristics of different fuels can impact the engine's efficiency and power output. If a particular fuel type results in more efficient combustion, it may contribute to better overall performance and potentially affect the slip ratio. On the other hand, the type of fuel can influence the torque and power characteristics of the engine. Changes in torque and power can, in turn, affect the rotational speed of the wheels and their tendency to slip. For example, a fuel that provides a more consistent and smooth power delivery might contribute to a more stable slip ratio.

It can be claimed that, according to the obtained results, a certain amount of ethanol improves fuel combustion efficiency, engine performance and fuel economy. Also, in tractors, adding ethanol in a certain range to the diesel fuel can prevent slippage.

The mutual effect of fuel combinations and gear level on the TE percentage

Figure 2 indicates the mutual effect of different fuel formulations on the traction efficiency percentage. According to Table 5, the impact of gear variation was practically on the TE percentage at a 1% level. As is clear from Fig. 4 shows, the increasing forward speed (by increasing gear from L1 to L3) reduced the traction efficiency. This trend is also reported by Ranjbarian et al. (2017)[43] and Battiato et al. (2017)[4]. Based on studies from different sources, the slip percentage is the main factor affecting the TE percentage. Accordingly, the maximum traction efficiency was obtained at B2E7, followed by B5E7, which was about 3 and 3.5% higher than the control. Based on Table 5, biodiesel and ethanol percentage in fuel formulation (at the 1% level) also successfully affected the TE percentage. This trend can be due to the biodiesel and ethanol's calorific value and oxygen content, which successfully affected the combustion efficiency[44–46]. Also, according to Table 1, the combination of ethanol and biodiesel successfully affected the fuel properties such as viscosity, cetane number, and calorific value. These parameters indicated an essential impact on engine performance[47–49], affecting the TE percentage.

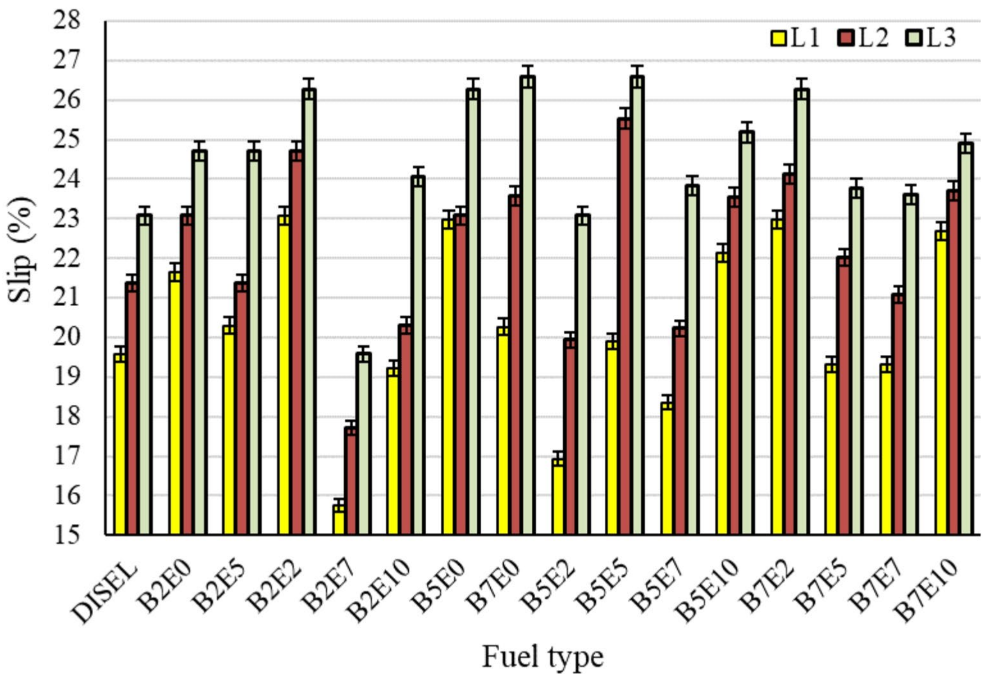


Fig. 1. The variation of slip (%) for each fuel type.

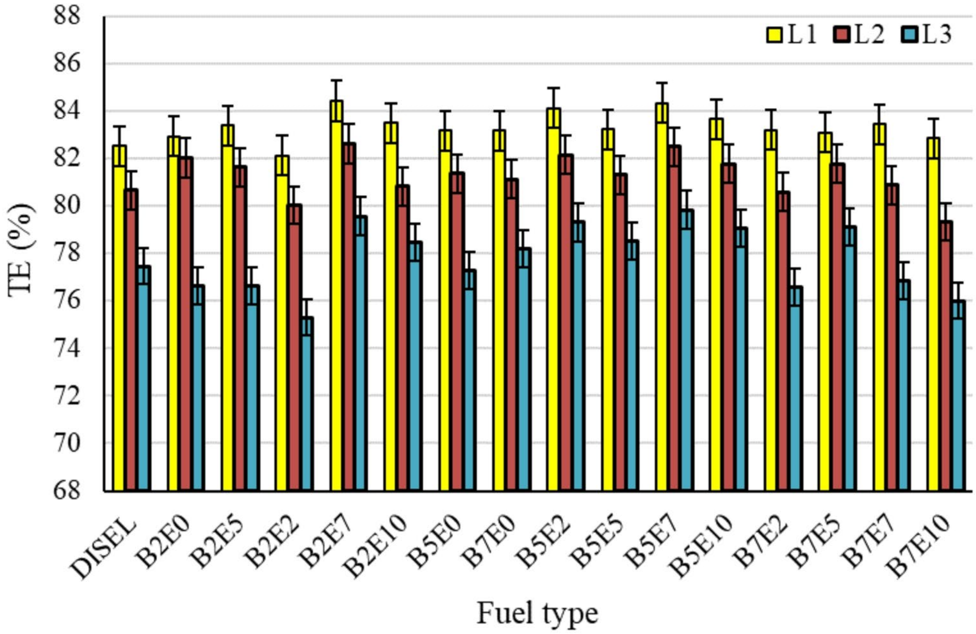


Fig. 2. The variation of TE (%) for each fuel type.

Based on the Eq. 3, both rolling resistance and slip have negative effect of traction efficiency (TE).

$$\mathrm{T.E.} = (1 - \mathrm{S})\left(1 - \sum \mathrm{R}/\mathrm{Ht}\right) \tag{3}$$

In which: R: rolling resistance, N, Ht: total traction force, N.

It should be considered that many parameters such as tire inflation pressure, tire forward speed, tire design and the load on tire and soil parameters such as its texture, moisture content, internal friction and adhesion are significant in rolling resistance. Then the optimum value of this parameters should be determined and by selecting the optimum values the rolling resistance can be reduced to save energy. Slipping aroud 7% is the optimum value in terms of traction and traction efichieny. Slipping less than 7% during agricultural operations can be achieved by deployment of very heavy tractors or highd load on tires. However, in this case, carrying excessive weights leads to increased fuel consumption and soil compaction, which are considered undesirable[50]. If the wheel drive slip exceeds 15%, it will result in severe soil compaction and reduced performance[51]. The changes in emissions and tensile efficiency (TE) can be explained by the chemical properties of the fuel; in particular, the high latent heat of vaporization of ethanol reduces the in-cylinder temperature, resulting in reduced NOx formation and increased CO, while the higher oxygen content in ethanol and biodiesel provides more complete combustion, helping to reduce CO and improve TE.

The mutual effect of fuel combinations and gear level on the emissions of the engine

Figure 3 presents the variety of CO emission by gear and fuel formulation. CO emission is the result of incomplete combustion. Figure 3 shows that, in general, the emission of CO increases with an increase in the percentage of ethanol in the fuel. Yilmaz also observes this trend by comparing the effects of biodiesel, ethanol, and methanol in diesel fuel. Accordingly, increasing the ethanol percentage in fuel samples increased the CO emission[45]. Krishna et al. also reported an optimum level of ethanol percentage in biodiesel and diesel fuel blends for a low CO emission. The results claimed that increasing the ethanol percentage increased the CO emission[52].

But with biodiesel's rise, carbon monoxide emission decreases relatively compared to diesel fuel. But the effect of ethanol on carbon monoxide emission is far more than that of biodiesel on carbon monoxide emission diesel fuel. This trend is also shown in Table 5. So that the development of ethanol on the emission of carbon monoxide is significant at the probability level of 1%, but the impact of biodiesel on the emission of carbon monoxide is substantial at the probability level of 5%. One of the reasons for this trend is the decrease in combustion temperature caused by the latent heat of ethanol vapor compared to the state without ethanol, which is more evident in the direction of high percentages of ethanol, which is also reported by Yang et al.[53].

Figure 4 presents the emission of CO2 by changing the gear and fuel combination. CO2 pollution is one of the combustion products of diesel engines. According to Table 5, the effect of ethanol changes on carbon dioxide emission is higher than the effect of biodiesel changes. One of the reasons is the shortest interval between biodiesel treatments, which cannot show its impact correctly. Also, Fig. 4 shows that the increase in the percentages of biodiesel and ethanol relatively increased CO2 emission slightly considering the control fuel and then decreased. Subbaiah et al. reported increased CO2 emission with biodiesel addition[54]. de Oliveira et al.

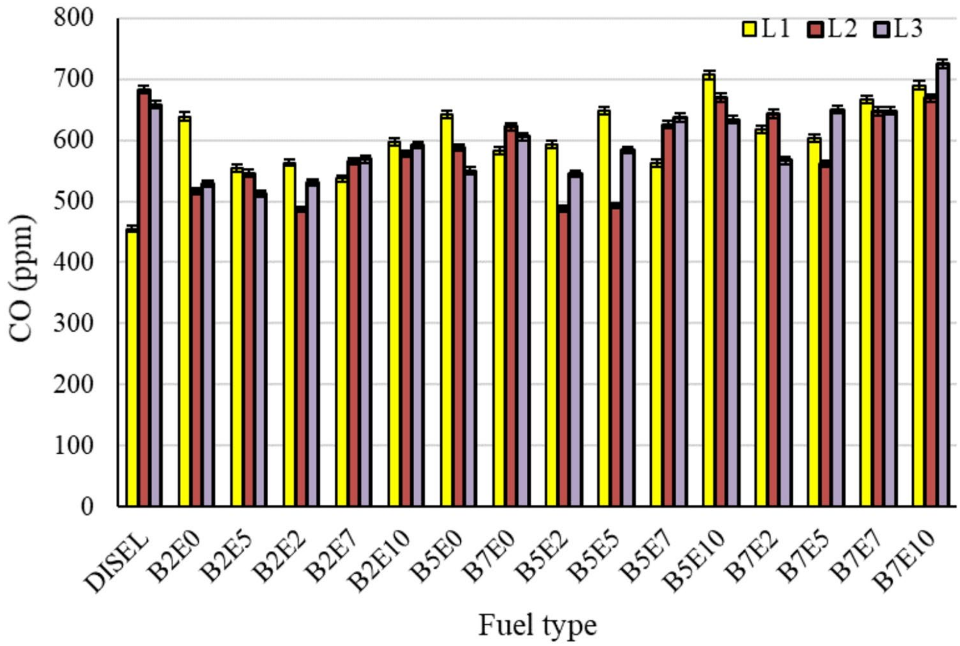


Fig. 3. The variation of CO (ppm) emission for each fuel type.

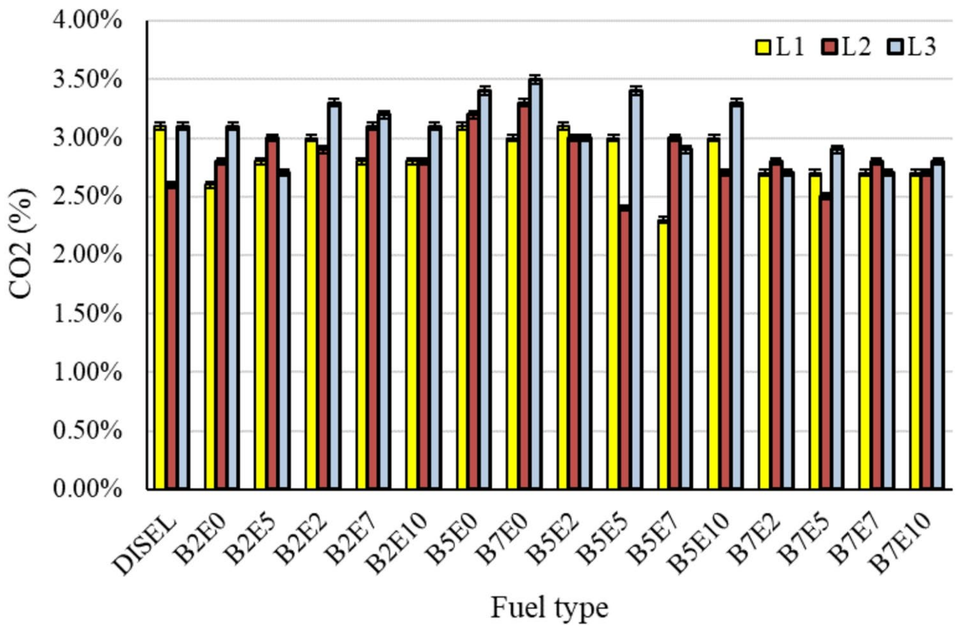


Fig. 4. The variation of CO2 (%) emission for each fuel type.

reported the opposite trend since the fuel sample in the presence of ethanol has a low ratio of carbon to hydrogen and high oxygen and improves the combustion process[55].

In contrast, the CO2 emissions increase is rooted in improving combustion[56,57]. The combustion process moves towards a complete circle by enhancing the combustion process due to oxygen in the biodiesel and ethanol fuel content. It causes carbon monoxide to be converted to carbon dioxide. However, with the increase in the percentage of ethanol, the combustion temperature caused by the latent heat of evaporation of ethanol decreases, and the formation of carbon monoxide increases. As a result, the amount of carbon dioxide emission decreases.

According to Fig. 4, increasing the gear level (from L1 to L3) relatively increases CO2 emission. Increasing the gear level increases, the engine load and pressure into the combustion chamber, leading the combustion to complete combustion and emitting more CO2.

Figure 5 presents the emission of NOx by changing the gear and fuel combination. According to the obtained results, with the addition of ethanol and biodiesel, the emission of NOx increases relatively because of the effect of biodiesel on NOx formation[58], especially at high loads[59], and then decreases (compared to the control fuel), because of the increase of ethanol. This trend was also reported by Randazzo et al.[60]. Also, based on Table 5, it can be claimed that the effects of changes in ethanol and biodiesel in the emission of NOx are significant at the 1% probability level. The emission of NOx is directly related to the thermal concentration inside the combustion chamber. Hence, the increase in temperature concentration inside the combustion chamber increases the emission of NOx[61,62]. Based on what was mentioned in the previous section, it can be said that increasing the percentage of ethanol in the fuel causes a decrease in the temperature inside the combustion chamber and, accordingly, can affect the formation of NOx. This was also observed in the study by Khoobbakht et al.[63].

In other words, it indicates that the starting temperature at the bottom of the compression stroke may significantly decrease because of the high latent heat of evaporation of ethanol. As a result, the local high temperature will drop due to the integrated fuel samples combustion system's more homogeneous mixture. On the other hand, the homogeneous mixture and the oxygen concentration in the ethanol favorably impact the opacity of the emissions[64].

According to Fig. 5, increasing the gear level (from L1 to L3) relatively increases the NOx emission. Because increasing the gear level enhances the engine load and on the other hand, enhances the temperature and pressure of the combustion chamber. These trends have led to the box formation.

Optimization results

This section presents the optimization results performed using the RSM technique to obtain the working condition and fuel formulation that make the best performance and the lowest emission. RSM was conducted with a design expert by fitting a quadratic equation. Figure 6 presents the optimized level for each variable. As there are three independent variables, triple mutual effects of independent variables have been considered. Accordingly, the optimized condition for obtaining the highest performance and the lowest emission is a fuel with a formulation of 0.2% ethanol and 4.1% biodiesel (B4.1E0.2) at a gear close to 3. It indicates that the L3 refers to the higher engine load, and higher engine loads guide the best diesel engine performance. This claim is also presented in a study by Najafi et al. (2019). Table 6 shows the dependent variables' optimized levels compared with the control values.

According to Table 7, the optimized condition could reduce the slip percentage by 8.5% and increase the TE percentage by 3%. Also, the optimized level could reduce CO, and NOx emissions by 13.5, and 0.48%, respectively.

Conclusion

The study aimed to examine the effect of biodiesel, diesel, and ethanol blends on an agricultural tractor engine's performance and emission characteristics in farming operation conditions. In the present study, the first step was on-farm experiments. The second step was optimizing the statistical results to obtain an optimized working condition for maximum performance and minimum emissions. The innovation of this research is that the efficiency and emissions of diesel-biodiesel-ethanol blended fuels were investigated under real field conditions,

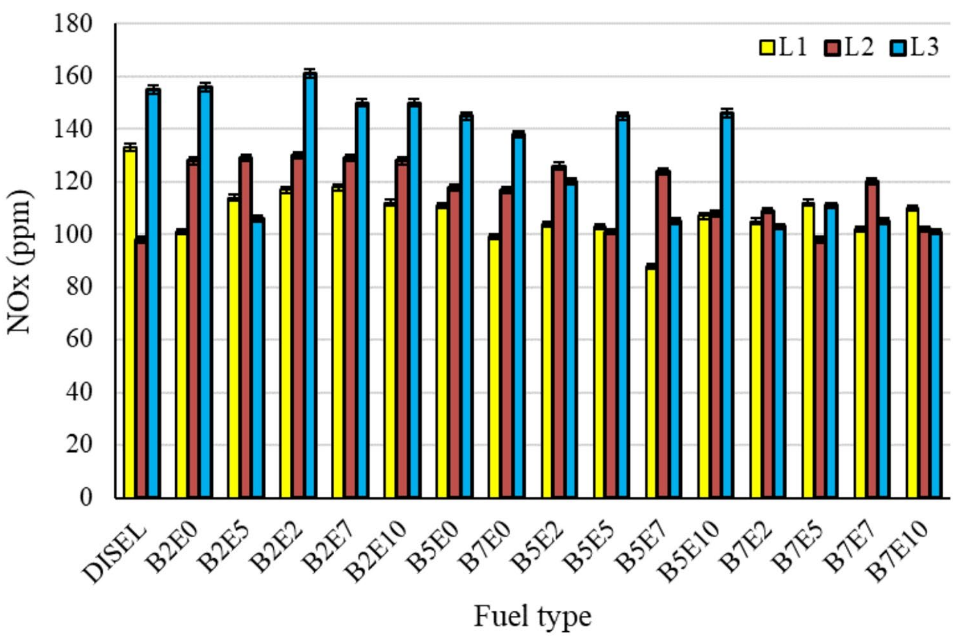


Fig. 5. The variation of NOx (ppm) emission for each fuel type.

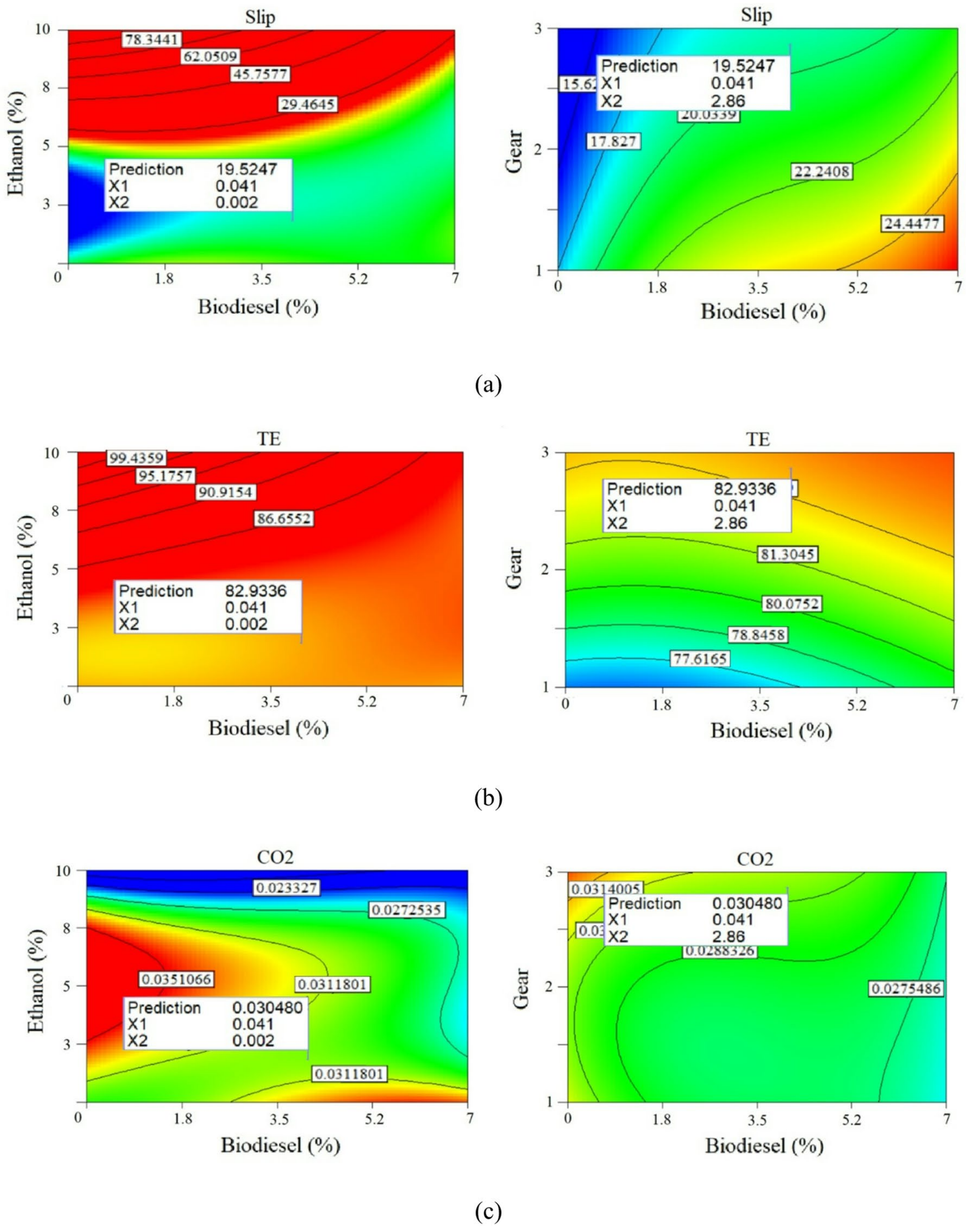
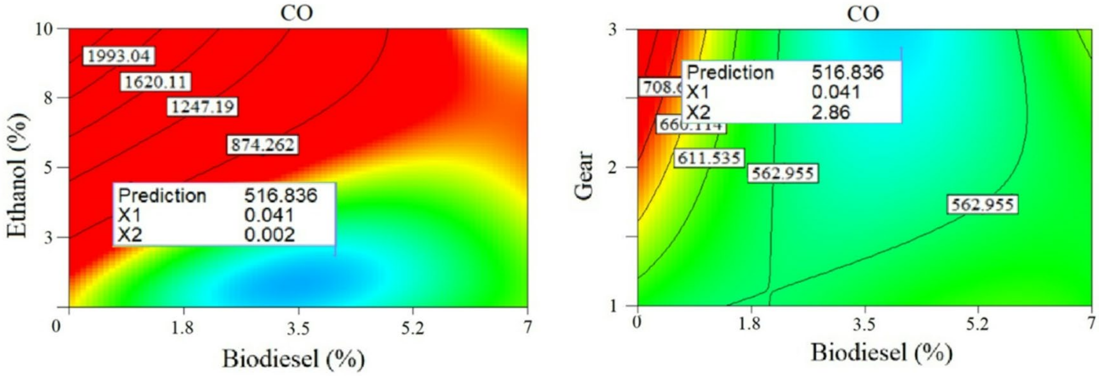


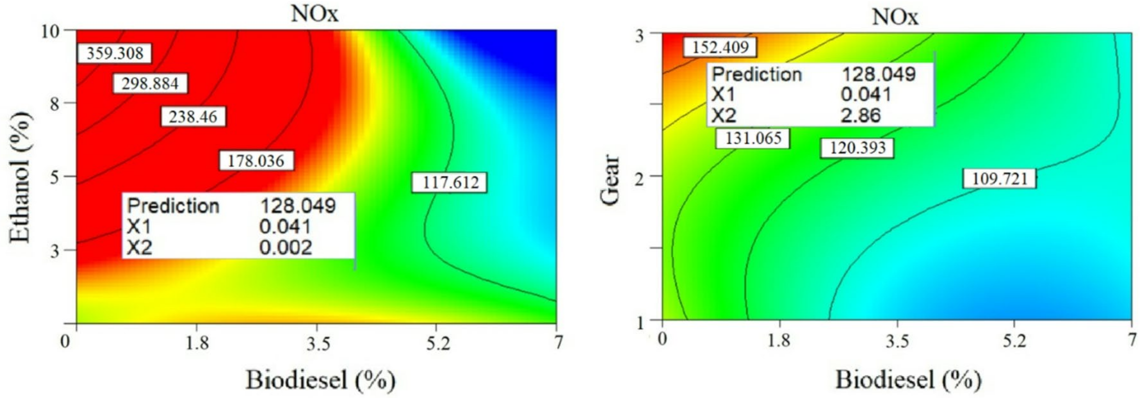
Fig. 6. The optimization level for each parameter; (**a**) slip (%); (**b**) TE (%); (**c**) CO_2 (%); (**d**) CO (ppm); (**e**) NOx (ppm).

and the results showed significant differences and overlaps with previous laboratory studies. In general, the following results have been received:

- The interactive effect of biodiesel and ethanol was significant on slip percentage, CO2 emission, and CO emission, and the interactive effect of biodiesel and gear was practical on traction efficiency.
- Increasing the gear level increased the slip percentage. B2E7 provided the lowest slip percentage compared to the control (about 15, 17, and 19%, respectively, for L1, L2, and L3).



(d)



(e)

Fig. 6. (continued)

	Slip	TE	CO2	CO	NOX
Control	21.3392	80.20922	0.029333	598.6667	128.6667
Optimized	19.52	82.93	0.0304	516.83	128.04
Variation (%)	8.52516	− 3.3921	− 3.63636	13.66982	0.487047

Table 7. A comparison of control value with the optimized level.

- Increasing forward speed (increasing gear from L1 to L3) reduced the traction efficiency. The maximum traction efficiency was obtained at B2E7, followed by B5E7, which were, on average, about 3 and 3.5% higher than the control, respectively.
- With an increase in the percentage of ethanol, the CO emission rises compared with the control. But with an increase in biodiesel, carbon monoxide emission decreases relatively compared to diesel fuel. The effect of ethanol changes on carbon dioxide emission is higher than that of biodiesel changes.
- An increment in the percentage of ethanol, the combustion temperature caused by the latent heat of evaporation of ethanol decreases, and the formation of carbon monoxide increases. As a result, the amount of carbon dioxide emission decreases.
- Addition of ethanol and biodiesel, the emission of nitrogen oxides increases relatively because of the effect of biodiesel on NOx formation, especially at higher loads, and then decreases (compared to the control fuel) because of the increase of ethanol.
- The optimized condition for obtaining the highest performance and the lowest emission is a fuel with a formulation of 0.2% ethanol and 4.1% biodiesel (B4.1E0.2) at a gear of 3. This level could successfully reduce the slip percentage, CO, and NOx emissions by 13.5, and 0.48%, respectively, and increases the TE percentage by about 3%.

In general, it can be concluded that higher tractor performance and lower engine emissions require both ethanol and biodiesel blends in diesel fuel. But, ethanol is needed at a lower percentage to improve the fuel samples' oxygen content. This study's contribution is to present a more detailed experiment to support a farming tractor's real-time performance and emission characteristics while operating in the presence of fuel samples containing diesel, biodiesel, and ethanol. The other essential contribution this research makes to the field is developing a real-time working approach that is both practical and adaptable to the decision-maker to gain a comparison of engine performance and emission metrics. The following are the two most significant advantages gained from conducting this study: (1) the practical information from the diesel engine of such a farm tractor fully prepared for farming purposes fueled with diesel–biodiesel–ethanol blends; and (2) discussion about the details of the technique.

RSM was used to carry out optimized fuel formulation to get the most effective fuel composition and a higher degree of flexibility with less labor-intensive experimentation. The most important point from this research is that fuels like diesel and biodiesel should have lower percentages of ethanol in their formulations. Lower ethanol content will increase the amount of oxygen that is present in the combustion chamber, which would, in turn, result in an improved combustion process. This approach is adaptable to various diesel engine configurations and operational environments. Fuel formulation, including a lower ethanol percentage, can improve the environmental impacts of the diesel engine and tractor performance in farming conditions which can be considered one of the main achievements of the current study.

Our future perspective is to test another additive for biodiesel fuel according to the results obtained. In the future experimental tests, we would like to analyze more parameters related to engine performance and emission characteristics such as specific fuel consumption, draw bar power, engine power, engine torque, UHC emission and soot emission. Also, we would like to develop a machine learning (ML) based system for reaching the farming tractor's optimized working conditions in a real-time concept. All these field tests help us to achieve this goal and make our research mapping more complete.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Received: 23 May 2025; Accepted: 10 November 2025
Published online: 29 December 2025

References

1. Malik, M. A. I. et al. Managing energy transition alongside environmental protection by making use of AI-led butanol powered SI engine optimization in compliance with SDGs, *Heliyon*, vol. 10, no. 9, (2024).
2. Schlosser, J. F. et al. Agricultural tractor engines from the perspective of Agriculture 4.0, *Revista Ciência Agronômica*, vol. 51, no. spe, p. e20207716, (2020).
3. Cutini, M. & Bisaglia, C. Development of a dynamometric vehicle to assess the drawbar performance of high-powered agricultural tractors. *J. Terrramech.* **65**, 73–84 (2016).
4. Battiato, A. & Diserens, E. Tractor traction performance simulation on differently textured soils and validation: A basic study to make traction and energy requirements accessible to the practice. *Soil Tillage. Res.* **166**, 18–32 (2017).
5. Moinfar, A., Shahgholi, G., Gilandeh, Y. A. & Gundoshmian, T. M. The effect of the tractor driving system on its performance and fuel consumption, *Energy*, vol. 202, p. 117803, (2020).
6. Šmerda, T. & Čupera, J. Tire inflation and its influence on drawbar characteristics and performance–Energetic indicators of a tractor set. *J. Terrramech.* **47** (6), 395–400 (2010).
7. De Araújo, V. F., da Cunha Honorato, A., Cortez, J. W., Patrocínio, A. P. & Filho De Jesus Nagahama, Patinagem, opacidade e ruído de três Tratores agrícolas de Pneus. *ENERGIA NA AGRICULTURA*. **29** (1), 01–08 (2014).
8. Cunha, J. P. B. et al. Efeito de diferentes concentrações de biodiesel Nas Emissões Gasosas de Um Trator agrícola Em operação. *Revista Brasileira De Ciências Agrárias*. **10** (4), 564–569 (2015).
9. Lima, L. P. et al., *Revista Engenharia na Agricultura-REVENG*, vol. 21, no. 5, pp. 447–455, (2013).
10. Malik, M. A. I. et al. Parametric optimization of engine performance and emissions for hydroxy blended gaseous fuels. *Energy Convers. Management: X*. **24**, 100796 (2024).
11. Seela, C. R., Kalabarige, L. R. & Kattela, S. P. Machine learning-based modeling of variable compression ratio engine performance and emissions with JME-ZnO nanoemulsion. *Energy Sour. Part A Recover. Utilization Environ. Eff.* **46** (1), 6038–6048 (2024).
12. Basu, C. *Biofuels and Biodiesel* (Springer, 2021).
13. Bux, F. *Biotechnological Applications of Microalgae: Biodiesel and value-added Products* (Crc, 2013).
14. Bajwa, W. et al. Optimization of biodiesel yield from waste cooking oil and sesame oil using RSM and ANN techniques, *Heliyon*, vol. 10, no. 15, (2024).
15. Sala, J. A. et al. Performance of a diesel engine using different biodiesel blends and injection configurations. *Revista Brasileira De Engenharia Agrícola E Ambiental*. **27** (1), 70–78 (2022).
16. Iamaguti, P. S., Lopes, A., Pinto, A. A. & Lira, T. A. M. d. Lima, agricultural tractor performance fueled with proportions of biodiesel. *Revista Ceres*. **69** (1), 1–6 (2022).
17. Tomić, M. et al. Effects of biodiesel on changes in IC engine performances: A long-term experiment with farm tractors. *Fuel* **292**, 120300 (2021).
18. Shevtsov, A., Tertychnaya, T., Serdyukova, N. & Tkach, V. Energy-efficient and environmentally friendly technology for producing fatty acid esters, in *IOP Conference Series: Earth and Environmental Science*, vol. 640, no. 4: IOP Publishing, p. 042008. (2021).
19. Ranganathan, B., Gopalasamy, S. & Shanmugasundaram, A. Air quality and waste management analysis of used ayurvedic oil in an off-road twin cylinder tractor engine. *Int. J. Sustain. Eng.* **14** (6), 2126–2136 (2021).
20. Nuanual, S., Maneechot, P., Thanarak, P., Phuruangrat, A. & Artkla, S. Physicochemical properties of Jatropha Podagrica biodiesel blends and their effects on tractor engine performance and emission. *Nature Environ. & Pollution Technology*, **19**, 4, (2020).
21. Hwang, J., Qi, D., Jung, Y. & Bae, C. Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. *Renew. Energy*. **63**, 9–17 (2014).
22. Karin, P. et al. Influence of ethanol-biodiesel blends on diesel engines combustion behavior and particulate matter physicochemical characteristics. *Case Stud. Chem. Environ. Eng.* **6**, 100249 (2022).

23. Adrian, V. N., Catalin, N. D. & Radu, C. On some possible effects of using renewable oxygenated fuels in a large marine diesel engine. *Energy Rep.* **8**, 966–977 (2022).
24. Liang, J., Zhang, Q., Ma, Q., Chen, Z. & Zheng, Z. Effect of various ethanol/diesel cosolvents addition on combustion and emission characteristics of a CRDI heavy diesel engine. *Energy Rep.* **8**, 735–748 (2022).
25. Zhong, Y., Zhang, Y., Mao, C. & Ukaew, A. Performance, combustion, and emission comparisons of a high-speed diesel engine fueled with biodiesel with different ethanol addition ratios based on a combined kinetic mechanism, *Processes*, vol. 10, no. 9, p. 1689, (2022).
26. Kalwar, A., Singh, A. & Agarwal, A. K. Potential of Di-Ethyl ether in reducing emissions from Heavy-Duty tractors. *SAE Tech. Paper*, 0148–7191, (2023).
27. Vedhagiri, V., Nallusamy, N. & Nagapandiselvi, P. Reduction of vibration and noise pollution from agricultural tractor engine using novelPine oil and soapnut oil methyl ester as fuel, (2022).
28. Al-Aseebee, M. D., Akol, A. M. & Naje, A. S. Performance evaluation of tractor engine using waste vegetable oil biodiesel for agricultural purpose. *Ecological Eng. & Environ. Technology*, **24**, (2023).
29. Janulevičius, A., Juostas, A. & Pupinis, G. Tractor's engine performance and emission characteristics in the process of ploughing. *Energy. Conv. Manag.* **75**, 498–508 (2013).
30. Simikic, M. et al. Influence of biodiesel on the performances of farm tractors: experimental testing in stationary and non-stationary conditions. *Renew. Energy*. **121**, 677–687 (2018).
31. Janulevičius, A., Šarauskis, E., Čiplienė, A. & Juostas, A. Estimation of farm tractor performance as a function of time efficiency during ploughing in fields of different sizes. *Biosyst. Eng.* **179**, 80–93 (2019).
32. Sahoo, P. et al. Comparative evaluation of performance and emission characteristics of jatropha, Karanja and Polanga based biodiesel as fuel in a tractor engine. *Fuel* **88** (9), 1698–1707 (2009).
33. Najafi, B., Faizollahzadeh Ardabili, S., Mosavi, A., Shamshirband, S. & Rabczuk, T. J. E. An intelligent artificial neural network-response surface methodology method for accessing the optimum biodiesel and diesel fuel blending conditions in a diesel engine from the viewpoint of exergy and energy analysis, **11**, 4, p. 860, (2018).
34. Najafi, B., Faizollahzadeh Ardabili, S., Shamshirband, S. & Chau, K. and T. J. E. A. o. C. F. M. Rabczuk, Application of ANNs, ANFIS and RSM to estimating and optimizing the parameters that affect the yield and cost of biodiesel production, vol. 12, no. 1, pp. 611–624, (2018).
35. Peça, J. O. et al. Speed advice for power efficient drawbar work. *J. Terrramech.* **47** (1), 55–61 (2010).
36. Damanauskas, V. & Janulevičius, A. Differences in tractor performance parameters between single-wheel 4WD and dual-wheel 2WD driving systems. *J. Terrramech.* **60**, 63–73 (2015).
37. Russini, A. & Schlosser, J. F. d. Farias, Estimation of the traction power of agricultural tractors from dynamometric tests. *Ciência Rural*. **48** (04), e20170532 (2018).
38. Hajlari, S. A., Najafi, B. & Ardabili, S. F. Castor oil, a source for biodiesel production and its impact on the diesel engine performance. *Renew. Energy Focus*. **28**, 1–10 (2019).
39. Karimi, P. et al. Ethyl ester production from Iranian bitter almond (BAO) oil to improve the performance and emissions of OM457 diesel engine. *Renew. Energy Focus*. **33**, 16–22 (2020).
40. Mamkagh, A. Effect of plowing speed, disk angle and Tilt angle on farm tractor wheel slip and on plowing depth using disk plow. *Jordan J. Agricultural Sciences*, **5**, 3, (2009).
41. Tayel, M., Shaaban, S. & Mansour, H. Effect of plowing conditions on the tractor wheel slippage and fuel consumption in sandy soil. *Int. J. ChemTech Res.* **8** (12), 151–159 (2015).
42. Mamkagh, A. M. Effect of soil moisture, tillage speed, depth, ballast weight and, used implement on wheel slippage of the tractor: A review. *Asian J. Adv. Agricultural Res.* **9** (1), 1–7 (2019).
43. Ranjbarian, S., Askari, M. & Jannatkhah, J. Performance of tractor and tillage implements in clay soil. *J. Saudi Soc. Agricultural Sci.* **16** (2), 154–162 (2017).
44. Yilmaz, N., Vigil, F. M., Donaldson, A. B. & Darabseh, T. Investigation of CI engine emissions in biodiesel–ethanol–diesel blends as a function of ethanol concentration. *Fuel* **115**, 790–793 (2014).
45. Yilmaz, N. Comparative analysis of biodiesel–ethanol–diesel and biodiesel–methanol–diesel blends in a diesel engine, *Energy*, vol. 40, no. 1, pp. 210–213, (2012).
46. Khoobbakht, G., Karimi, M. & Kheiralipour, K. Effects of biodiesel-ethanol-diesel blends on the performance indicators of a diesel engine: A study by response surface modeling. *Appl. Therm. Eng.* **148**, 1385–1394 (2019).
47. Attia, A. M., Nour, M. & Nada, S. Study of Egyptian castor biodiesel-diesel fuel properties and diesel engine performance for a wide range of blending ratios and operating conditions for the sake of the optimal blending ratio. *Energy. Conv. Manag.* **174**, 364–377 (2018).
48. Chattopadhyay, S. & Sen, R. Fuel properties, engine performance and environmental benefits of biodiesel produced by a green process. *Appl. Energy*. **105**, 319–326 (2013).
49. Faizollahzadeh Ardabili, S., Najafi, B. & Shamshirband, S. Fuzzy logic method for the prediction of cetane number using carbon number, double bounds, iodic, and saponification values of biodiesel fuels. *Environ. Progress Sustainable Energy*. **38** (2), 584–599 (2019).
50. Janulevičius, A., Damanauskas, V. & Pupinis, G. Effect of variations in front wheels driving lead on performance of a farm tractor with mechanical front-wheel-drive. *J. Terrramech*. **77**, 23–30 (2018).
51. Moitzi, G., Haas, M., Wagentristl, H., Boxberger, J. & Gronauer, A. Energy consumption in cultivating and ploughing with traction improvement system and consideration of the Rear furrow wheel-load in ploughing. *Soil Tillage. Res.* **134**, 56–60 (2013).
52. Krishna, S. M., Salam, P. A., Tongroon, M. & Chollacoop, N. J. A. T. E. Performance and emission assessment of optimally blended biodiesel-diesel-ethanol in diesel engine generator, vol. 155, pp. 525–533, (2019).
53. Yang, P. M. et al. Comparison of carbonyl compound emissions from a diesel engine generator fueled with blends of n-butanol, biodiesel and diesel, **90**, pp. 266–273, (2015).
54. Subbaiah, G. V. et al. Rice bran oil biodiesel as an additive in diesel-ethanol blends for diesel engines, vol. 3, no. 3, pp. 334–342, (2010).
55. de Oliveira, A., de Morais, A. M., Valente, O. S., J., J. R. & Sodré, F. P. T. Combustion characteristics, performance and emissions from a diesel power generator fuelled by B7-ethanol blends, vol. 139, pp. 67–72, (2015).
56. Zareh, P., Zare, A. A. & Ghobadian, B. Comparative assessment of performance and emission characteristics of castor, coconut and waste cooking based biodiesel as fuel in a diesel engine, *Energy*, vol. 139, pp. 883–894, (2017).
57. Can, Ö., Öztürk, E. & Yücesu, H. S. Combustion and exhaust emissions of Canola biodiesel blends in a single cylinder DI diesel engine. *Renew. Energy*. **109**, 73–82 (2017).
58. Palash, S. et al. Impacts of biodiesel combustion on nox emissions and their reduction approaches. *Renew. Sustain. Energy Rev.* **23**, 473–490 (2013).
59. Chen, H., Xie, B., Ma, J. & Chen, Y. NOx emission of biodiesel compared to diesel: higher or lower? *Appl. Therm. Eng.* **137**, 584–593 (2018).
60. Randazzo, M. L. & Sodré, J. R. Exhaust emissions from a diesel powered vehicle fuelled by soybean biodiesel blends (B3–B20) with ethanol as an additive (B20E2–B20E5), *Fuel*, **90**, 1, pp. 98–103, (2011).
61. Hoekman, S. K. & Robbins, C. Review of the effects of biodiesel on nox emissions. *Fuel Process. Technol.* **96**, 237–249 (2012).

62. Al-Dawody, M. F. & Bhatti, S. Optimization strategies to reduce the biodiesel nox effect in diesel engine with experimental verification. *Energy. Conv. Manag.* **68**, 96–104 (2013).
63. Khoobbakht, G., Najafi, G., Karimi, M. & Akram, A. Optimization of operating factors and blended levels of diesel, biodiesel and ethanol fuels to minimize exhaust emissions of diesel engine using response surface methodology. *Appl. Therm. Eng.* **99**, 1006–1017 (2016).
64. Lu, X., Ma, J., Ji, L. & Huang, Z. Simultaneous reduction of NOx emission and smoke opacity of biodiesel-fueled engines by port injection of ethanol, *Fuel*, vol. 87, no. 7, pp. 1289–1296, (2008).

Author contributions

A.Sh. : Writing – review & editing. Gh.Sh : Writing – original draft, Supervision, Investigation. S.A. : Writing – original draft and review & editing, Methodology, Investigation, Formal analysis, Data curation, Visualization. A.K. : Writing –original draft, Visualization, Validation, Software, Formal analysis.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to G.S. or S.A.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.