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Research article

Impact of additives from moringa stenopetela leaf extract and ethanol on the emission characteristics and performance of soybean biodiesel for single cylinder CI engine

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A R T I C L E I N F O

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A B S T R A C T

The study investigates the effect of ethanol and Moringa antioxidant on the performance and emission characteristics of a Soybean biodiesel blend (B15, B20, and B25) using a direct injection, four-stroke, naturally aspirated, water-cooled single-cylinder diesel engine equipped with SCADA software. The effect of reaction parameters on FAEE yield such as, time, catalyst concentration, molar ratio of alcohol to oil, and blending quality, was optimized using the one factor at a time experimental technique. The maximum yield of 97.8% biodiesel was produced at the ideal catalyst concentration, blending quality, alcohol to oil molar ratio, and time of 1 h, are 1%, 12:1, and 500 rpm, respectively. The Rancimat method was used to assess the oxidative stability of pure biodiesel after the natural antioxidant (extracted from Moringa leaf) was added at concentrations of 1500, 2500, 3500, and 4500 ppm. The addition of antioxidants to biodiesel significantly increased its induction time from 4.52 to 19.98 h. Brake-thermal efficiency increased by 4.4% whereas brake-specific fuel consumptions decreased by 4.6% for B15E2M (15% SB+2E + M) when compared to B15. Emission characteristics of B25E2M showed higher reduction of CO, HC and NOx by 20.27%, 8% and 7% as compared to the B25 respectively. The physicochemical qualities, performance, and emission characteristics of B15 blends with additive are generally comparable to those of diesel fuel. In conclusion, both additives significantly improved the combustion performance of soybean biodiesel blend.

1. Introduction

Fossil fuels, including coal, gas, and crude oil, are the world's primary energy sources [1]. Air pollution and climate change are only two of the many environmental problems that have arisen from this reliance on fossil fuels. The negative consequences of air pollution, which result in major social and economic costs associated with human health, have brought these issues to the forefront [2]. Following this, a growing understanding of the energy challenges and environmental issues caused by the combustion of fossil fuels inspired many researchers to detect the potential of substituting fossil fuel and its derivatives with renewable energy [3].

Solar, geothermal, and tidal processes produce renewable energy on a continuous basis. It refers to clean, non-exhaustible, and mostly domestic sources of energy [4]. Biomass is a combustible renewable energy source that refers to organic material obtained from

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Nomenclature

ASTM	American Society for Testing and Materials
BNF	Biological nitrogen fixation
BSFC	Brake-specific fuel consumption
CO	Concentration of carbon monoxide
CO_2	Concentration of carbon dioxide
CP	Cloud point
EU	European biodiesel specification
FAEE	Fatty acid ethyl esters
CV	Calorific Value
UHC	Unburned hydrocarbon
IP	Induction period
NOx	Nitrogen oxide
OFAT	One factor at a time
PP	Pour point
RSE	Relative standard error
S_{Error}	Standard error
$\overline{X}$	Mean of the data collections

biological sources that is non-fossilized and biodegradable [5]. Biomass includes chemical energy stored from sunlight and can be transformed into primary transportation fuels such as biodiesel, cellulosic ethanol, green diesel, and others by applying the wide range of techniques [6]. Among these transportation fuels, biodiesel has become increasingly popular due to its environmental benefits.

The monoalkyl esters of long-chain fatty acids that make up biodiesel are biodegradable and non-toxic, which helps to significantly lower emissions of other pollutants and harmful substances when used as fuel. Biodiesel has several noteworthy benefits, such as ease of transportation, increased combustion efficiency, low toxicity, elevated flash point, decreased sulphur and aromatic content, increased cetane number, and enhanced biodegradability [7]. Numerous feedstocks can be used to make biodiesel. These feedstocks consist of animal fats like tallow and waste oils like frying oils, along with vegetable oils like peanut, rapeseed/canola, soybean, sunflower, palm, safflower, cottonseed, and coconut [8].

Among those feedstocks, Soybean is a highly valued crop worldwide and is considered as an essential source of plant protein. This annual crop, which belongs to the Leguminosae family, has an outstanding capacity to naturally protect itself against insects and illnesses, making it a favorite choice among farmers. Soybean inoculation with rhizobacteria promotes biological nitrogen fixation, resulting in increased yields while reducing fertilizer inputs. Biological nitrogen fixation (BNF) is regarded as the most sustainable and low-cost natural technique of obtaining nitrogen. Soybean grows to a height of 180 cm as a self-pollinated plant species, and its cultivation has multiple advantages, including global accessibility and adaptation to varied soil types, rainfall patterns, and temperature variations [9].

Due to its easy availability and desirable physicochemical properties, soybean biodiesel is one of the most widely used biodiesels in many countries. When compared to animal fat biodiesel, it is non-toxic, biodegradable, renewable, has higher flashpoint, lubricious, and minor effect to environment [10]. Soybean biodiesel shares many of the same physical and chemical characteristics as diesel fuel. In comparison to diesel fuel, soybean biodiesel has a higher cetane number, contains no aromatics, 10–11% oxygen by weight, and almost no sulphur. These fuel properties lower emissions of hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) in the exhaust gas as compared to diesel fuel [11,12].

However, soybean biodiesel has some inherited disadvantages beyond its advantages, such as higher density and viscosity, lower heating value, low cold flow property, and poor oxidative stability due to the polyunsaturated fatty acids present in soybean seeds [13], and it causes to react with atmospheric oxygen and produces caustic carboxylic acid, which damages engine components such as valves, piston rings, and anodes [14]. Furthermore, because of the reduction in heating value and increased NOx emissions while increasing the percentage of soybean biodiesel fuels, it has low BTE and higher BSFC [15].

To address this issue, researchers have used a variety of approaches, including exhaust gas recirculation [16], water emulsion with ZnO nanoparticles [17,18], water with soybean biodiesel [10], and antioxidants with soybean biodiesel [19]. Furthermore, the production of particular products that adhere to local and national requirements depends on fuel additives in addition to helping to mitigate these shortcomings [20]. Fuel additives are classified into six types: metal-based, oxygenated, cetane number improver, ignition boost, lubricant, and antioxidants. Oxygenated additions boost engine combustion and performance; however, antioxidant compounds are more beneficial for increasing biodiesel stability, lowering NOx emissions and lowering cylinder temperature [21,22].

Antioxidant chemicals are frequently used in the food, cosmetic, and pharmaceutical sectors, as well as biodiesel blends, in order to prolong product shelf life by preventing oxidative processes. Synthetic antioxidant additions, on the other hand, are usually expensive non-biodegradable, and hazardous to both human health and the environment. Hence, there is an urgent requirement to find low-cost, environmentally favorable alternatives produced from biomass or waste materials. This motivation not only helps to reduce expenses and environmental impact, but it also promotes strategies of sustainable development [23].Among these are the well-known renewable ingredients moringa stenopetela leaf antioxidant and ethanol. Natural antioxidants have been identified to improve the oxidative stability and performance of biodiesel [24,25]. To improve combustion performance and emission characteristics, numerous researchers test different combinations of biodiesel and additives. Development of bioprocess operational modes and strain enhancement will be necessary for future bioethanol production from a variety of renewable biomass feedstock. Another method for improving combustion efficiency and emission characteristics is exhaust gas recirculation (EGR) [26–30].

When 100 μggˆ(−1) of M. oleifera leaf ethanoic extract was used, the IP values of soybean biodiesel increased from 3.8 to 10.3 h, exceeding the synthetic antioxidant tert-butyl-hydroquinone [24]. This indicates that the ethanoic extract of M. oleifera leaves is a valuable source of antioxidants for soybean oils. After Pongamia pinnata leaves were tested for their antioxidant capacity on Jatropha biodiesel and its diesel blends, it was found that JME20 PLA3 tested fuel has a 21.1% increase in brake-specific fuel consumption (BSFC) at full load. The JME20 PLA4 engine's maximum load reduces emissions by 17.5% for unburned hydrocarbon (HC) and 16.3% for smoke. In the coated engine for JME20 with 2000 ppm, nitric oxide (NO) emissions are decreased by 16% [31].

In addition to being sulphur-free and having a high percentage of oxygen in its composition to assist reduce particulate matter emissions, ethanol is a clean energy source that can theoretically be used in small amounts with diesel fuel and biodiesel blends [32]. According to research, adding more ethanol to soybean biodiesel/diesel blends increased exhaust gas emissions by 1.4 times while lowering maximum torque and power by 6% [33]. Diesel oil containing 20% biodiesel (B20) and ethanol at concentrations of 5, 10, and 20% was used to run a diesel engine. The experimental results showed that adding more ethanol decreased the amount of fuel used specifically for the brakes while increasing brake thermal efficiency and significantly reducing soot [34].

The physicochemical characteristics of soybean seed oil and its ethyl ester were investigated in this work and contrasted with EU and ASTM standards. Additionally, the impact of varying concentrations of the antioxidant moringa stenopetela on the oxidative stability of soybean biodiesel was investigated. The influence of ethanol and Moringa leaf extracted additives on the performance and emission characteristics of soybean biodiesel/diesel was studied. Finally, the results were compared to the standard diesel fuel.

2. Materials and methods

2.1. Experimental setup

For the engine performance test, the single-cylinder compression ignition engine depicted in Fig. 1 is used. Internal combustion engines with a maximum power output of 7.5 KW are tested for this investigation using a computer-controlled test bench with a single cylinder. Supply voltage can be adjusted by changing the torque properties of the loading torque using the electromagnetic eddy current brake on the dynamometer. The device has several sensors that provide measured values for the variables under investigation. Temperature and speed conditions are vary at different points on the test bench to determine the fuel flow rate, power, and torque. For any given speed, this leads to the generation of power or torque curves. This computer-controlled apparatus consists of a control interface box, a data acquisition board, an eddy current type dynamometer, computer control, data management software packages, and information acquisition for parameter regulation.

2.2. Synthesis of soybean biodiesel

Soybean oil was extracted from soybean seeds using a mechanical press. With the use of a screw oil press, soybean oil was extracted and degummed to remove unwanted gum and wax combinations in order to improve physical stability and make additional processing easier. Furthermore, the degumming process begins with heating crude oil and distilled water separately at 80 and 50 °C, respectively. The mixture of distilled water and crude oil was then mixed and agitated at 500 rpm for 20 min before being placed into a separatory funnel. When the mixture was completely settled in a separator funnel, the oil and unwanted substances were separated by decantation, and the degummed oil was oven-dried and filtered with filter paper to remove the remaining unwanted substance. The overall degumming process is presented in Fig. 2(a-c) in detail.

Subsequently, ethanol and KOH are added during the transesterification process to make soybean biodiesel. Fig. 3(a and b) shows the generation of FAEE and the phase separation. The biodiesel that had been created was then put in a separator funnel and allowed to separate into two layers over night. Following settling, the crude biodiesel was cleaned at 90 °C using 30% (v/v) warm water, and any

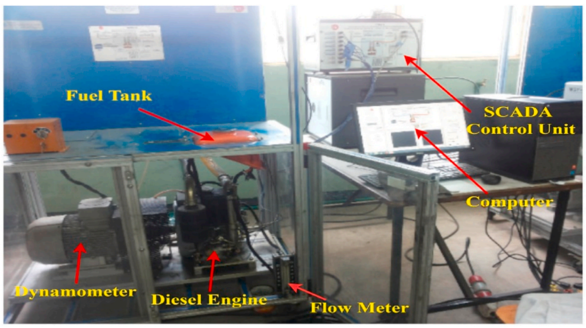

Fig. 1. Experimental setups of the TBMC8 test bench for single-cylinder diesel engine.

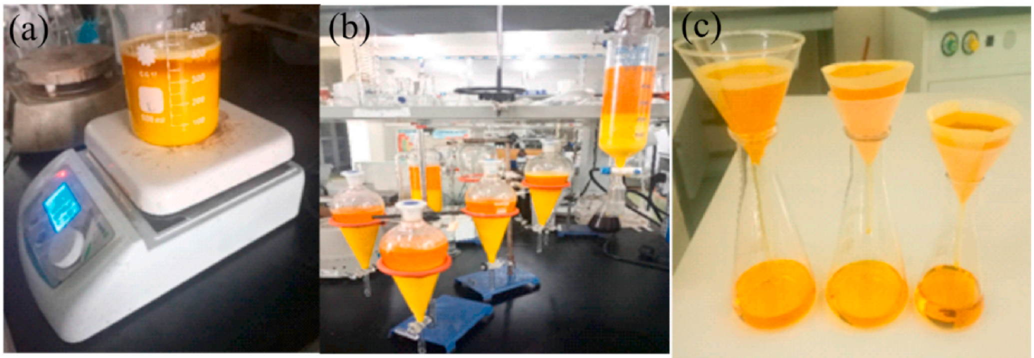

Fig. 2. (a) Mixing of distilled water with crude oil, (b) Decantation, (c) Pure oil.

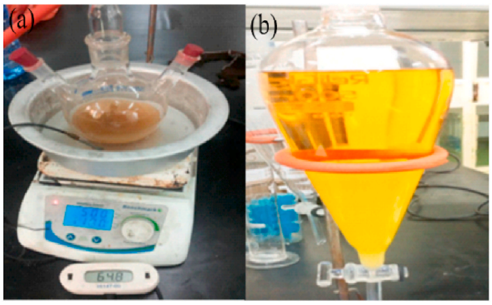

Fig. 3. (a) FAEE production, (b) FAEE phase separation.

remaining water was removed by placing the mixture in an oven set to 90 °C for 8 h [35]. The suitability of soybean biodiesel for use in diesel engines was then assessed using the recognised methods shown in Table 1. Therefore, the results were illustrated in Table 2.

To determine the most optimal conditions for maximum FAEE production, the OFAT (One factor at a time) experimental method was applied, which implies that one parameter was changed while the others remained constant. The transesterification reaction was carried out by maintaining a constant temperature throughout the experiment and varying the main parameters, which were reaction time (60mins, 90mins, 120mins, 150mins), catalyst concentration (1%, 1.5%, 2%, 2.5%), oil to methanol molar ratio (1:6, 1:9, 1:12 and 1:15), and reaction rate (500,1000,1500,2000 rpm).

2.3. *Fourier transform infrared spectroscopy test*

The identification of organic and inorganic chemical components in a sample is carried out by the Fourier transform infrared spectroscopy (FTIR) technique [36]. Infrared spectra is used to determine a compound's identity, evaluate its purity, and provide structural information [37]. Using Fourier transform infrared spectroscopy (FTIR), researchers found a number of novel functional groups. Functional group analysis of the soybean oil, biodiesel and diesel was determined using Fourier-Transformed Infrared spectroscopy (FTIR) as shown in Fig. 4. The instrument used was able to record spectra from wave numbers of 4000 to 500 cm-1.

To begin, a spectrum of the optical path was collected without the sample to understand the background information, followed by

Table 1
Biodiesel properties of EN 14214, ASTM D6751, and ASTM D975 standards [1–5].

Property	unit	EN-14214	ASTM-D6751	ASTM D975
		biodiesel	biodiesel	Diesel
Density at 15 °C	kg/m3	860–900	880	850
Viscosity at 40 °C	mm2/s	3.5–5.0	1.9 6.0	1.3–4.1 mm2/s
Calorific value in MJ/kg		35	min 40	42–46
Flash point	°C	120 –	130 min	325 K min
Acid number mg KOH/g	mg KOH/g	−0.50	– 0.5	
Iodine value	g I/100 g	−120		
Stability of oxidation at 110 °C	hours	6.0 –	– 3	
Pour point (∘C)			−15 to −16	−35
Cloud point (∘C)			−3 to −12	−20

Table 2
Physicochemical properties of soybean oil, FAEE and its blends.

Property	OIL	FAEE	FAEE with additive	B15	B20	B25	B15E2M	B20E2M	B25E2M	Diesel	EN-14214	ASTM D6751	ASTM D975
Density at 15 °C (kg/m^3)	910	890	885	840	843	848	835	639	845	830	860–900	880	850
Viscosity at 40°C (mm^2/s)	37.7	5.7	5.08	3.7	3.9	4.1	3.5	3.6	3.8	3.4	3.5–5.0	1.9–6.0	1.3–4.1
Calorific value (MJ/Kg)	–	42	41.6	46	45	44	47	45	44	48	35	Min40	42–46
Flash point (°C)	–	185	169	66	69	74	54	58	62	53	Min120	Min130	Min 52
Acid number mg KOH/g	1.36	–	–	–	–	–	–	–	–	–	Max 0.5	Max 0.5	
Iodine value	157.6	–	–	–	–	–	–	–	–	–	Max 120	–	–
Oxidative stability at 110 °C (hour)	–	4.5	19.98	–	–	–	–	–	–	–	Min 6	Max 3	
Pour point (∘C)	–	−3.5	−2.5	–	–	–	–	–	–	–		−15 to −16	−35
Cloud point (∘C)	–	−7.2	6.2	–	–	–	–	–	–	–		−3 to −12	−20
Saponification value (mg KOH/g)	193.8	–	–	–	–	–	–	–	–	–	–	–	–

the specimen was put in the infrared beam path for analyzing its spectrum. The software co-added the electromagnetic spectrum with the sample and the background before Fourier-transforming it to produce the desired FTIR spectrum. finally, the machine was cleaned using acetone.

2.4. Preparation of the antioxidant additive

For usage as an antioxidant to increase combustion stability, moringa leaves were collected from the Arba Minch University research Centre and processed. The extraction of Moringa antioxidant was carried out in accordance with D. M. Fernandes et al. [24], with a few adjustments. The overall preparation of antioxidant additive is as presented in Fig. 5(a–h). The leaves were detached from the stalks and sun dried. The dried sample was crushed with a coffee crusher. The sample was then sieved to the required mesh size and stored in a plastic bag for the next the test. The sample (50 g) was mixed with 200 mL of 99% ethanol in the flask in a 1:4 (g/mL) ratio and placed in the ice bath, with the horn of the sonicator immersed inside the sample. The extracted liquid was then filtered, the water was eliminated by lyophilization, and the solvent was eliminated by rotator evaporation at 40 °C. The antioxidant component was transferred to amber flasks and kept at 4 °C until analyzed. The extracted yield was 12.53% for 99.9% ethanol.

The oxidative stability of the biodiesel with different concentration of moringa stenopetala leaf extract was performed using 892 professional rancimant as shown in Fig. 6.

2.5. Engine performance test and emission characteristics of FAEE blends

A four-stroke, direct-injection, naturally aspirated, water-cooled, single-cylinder diesel engine with SCADA software was used for the experiment. For B15, 20B, and B25, constant volume percentage ethanol 2% and 1500 ppm Moringa Stenopetela antioxidant additives (B25E2M, B20E2M, and B25E2M, respectively) were added as shown in Fig. 7.

The engine, which, is specified in Table 3, was then subjected to a series of fuel tests ranging from zero load to 80% load with a 10% increment. Consequently, the studies were carried out using diesel alone, blends of biodiesel with and without additives. Hence, the efficiency and emissions of a single-cylinder diesel engine were tested using diesel, soybean biodiesel, and soybean biodiesel enhanced by additives. The blends' fuel qualities were examined using standard ASTM procedures, and engine emissions were measured at various speeds and loads using KANE AUTO plus V1.00 exhaust gas analyzer, which is specified in Table 4.

2.6. Uncertainty analysis of the measurement

The type of instruments used, the measurement technique, the surrounding circumstances, and the experimental setup are some of the variables that might lead to uncertainty in an experiment. After adjusting the engine loads and speed for 10 min, engine performance and emission measurements were carried out for each scenario to make sure the measured parameters didn't change. Five repetitions of the experiment were conducted for each fuel. The root mean square of experimental data uncertainty and instrumental uncertainty were utilized to estimate the overall uncertainty using parameters that were measured like brake torque, CO, CO2, and NOx [38]. To ensure the accuracy of the test results, an error analysis was conducted using Taylor's theorem, as Table 5 demonstrates. The level of uncertainty overall is indicated by equation (1).

$$Overall\ \ uncer\tan ity = \left(\sqrt{(\Delta BP)^2 + (\Delta BT)^2 + (\Delta BTE)^2 + (\Delta BSFC)^2 + +(\Delta CO)^2 + (\Delta CO_2)^2} \right. \tag{1}$$

Many of the variables in Table 5 had total measurement errors of less than 3.59%, or the 5% standard deviation limit.

Fig. 4. Fourier Transform Infrared Spectroscopy, is 50 ABX.

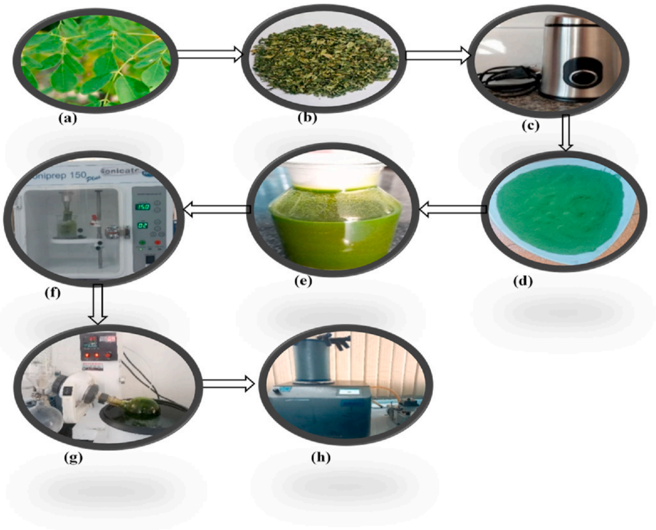

Fig. 5. Production process of moringa stenopetela leave extract of (a) M. Stenopetala leave, (b) Dried leave, (c) Coffee crusher, (d) Leave powder, (e) solution of leave and ethanol, (f) Sonicator, (g) Rotary evaporator and (h) Lyophilizer.

Fig. 6. Soybean ethyl ester and its blend with different concentration of Moringa Stenopetala leave extract.

Fig. 7. Blended fuels with and without additives.

Table 3
Engine Specification.

Engine Specification	
Type	single cylinder, 4-stroke
Displacement	309 c.c.
Bore × stroke	75 × 70 mm
Dry weight	54 kg
Cooling system	Water cooled (radiator)
Fuel	SAE No.2-D Light diesel oil
Lubrication system	Forced lubrication with trochoid
Rotational direction	Counter clockwise facing flywheel
Water cooling capacity	1.2L
Engine oil capacity	1.3L
Starting system	Electric start
Starter	12V 0.8kw
Injection pressure	180 bar
Engine max power	7.5 kW

Table 4
Product details for the portable Auto + 4-2 and AUTO + 5-2 [6].

Specifications	Resolution	Accuracy	Range
Carbon monoxide (infrared)	0.01%	±5% of reading^{-1}	0–10%
		±0.06 % volume^{-1}	Over range 20%
hydrocarbon (infrared)	1 ppm	±5% of reading^{-1}	0–5000 ppm
		±12 % volume^{-1}	Over range: 10,000 ppm
Carbon dioxide (infrared)	0.1%	±5% of reading^{-1}	0–16%
		±0.5 % volume^{-1}	Over range:25%
Nitric oxide (fuel cell)	1 ppm	0–1500 ppm ± 5% or 25 ppm	0–1500 ppm
			Over range: 5,000 ppm

Table 5
Analyses of uncertainty for various variables.

Parameter	Measurement Range	Level of Accuracy	uncertainty
Engine speed	1–3250	±0.2	±0.5
Brake thermal	–	±1Nm	±1.3
Brake powr	–	±0.03 KW	±0.5
Brake thermal efficiency	–	±0.5%	±1.7
Carbon monoxide	0–10%	±0.06%	±0.6
Hydrocarbon	0–5000 ppm	±12	±0.65
Carbon dioxide	0–16%	±0.5	±2.53
*Nitric oxide**2	0–1500 ppm	±10 ppm	±0.65
Carbon monoxide	0–15%	±0.06	±0.4

3. Result and discussion

3.1. Tests using Fourier transform infrared spectroscopy

Fig. 8 (B-D) and Table 6 show FT-IR spectra as well as the functional group compositional analysis for diesel, biodiesel, and soybean oil. The wave number and transmittance percentage were reported for C–H (2700-3000 cm-1), C═O (1500-1800 cm-1), and C–O (600-1400 cm-1), as well as for C–H rock (725 and 700 cm-1) bonds. The greater occurrence of the related chemical bonds in the samples is shown by a smaller proportion of transmittance in the graph [36,39]. The C–H stretching peaks have been detected at wave numbers of 2856 and 2925 cm-1 for oil, 2854 and 2923 cm-1 for biodiesel, and 2859 and 2927 cm-1 for diesel. These wave numbers correspond to the symmetric and asymmetric stretching vibrations of C–H alkane groups [40].

The existence of carbonyl groups in the triglycerides is responsible for the strong peak at 1745 cm1, which is caused by the C═O stretching vibration of the carbonyl groups, as shown in Fig. 8 (B). A rocking vibrational mode is present at the specific peak at 721.8 cm-1, where the = C–H groups overlapped. The biodiesel's rocking mode of vibration further demonstrates the basin structure of the FAEE component and suggests that the biodiesel is primarily made up of long-chain aliphatic molecules [41].

Due to the existence of triglycerides and esters, the FT-IR spectra of soybean oil and the biodiesel produced from it were comparable as presented in Fig. 8 (B, C). However, relatively slight variations were found, where the peaks in soybean oil that revealed at 1745, 1463, 1164, and 725 cm-1 were changed to 1736, 1463, 1176, and 721 cm-1 in biodiesel, respectively. Therefore, the formation of new peaks at 1372, 1098, and 1034 cm-1 in the produced biodiesel sample and the disappearance of the peaks at 1378, 1103, and 1081 cm-

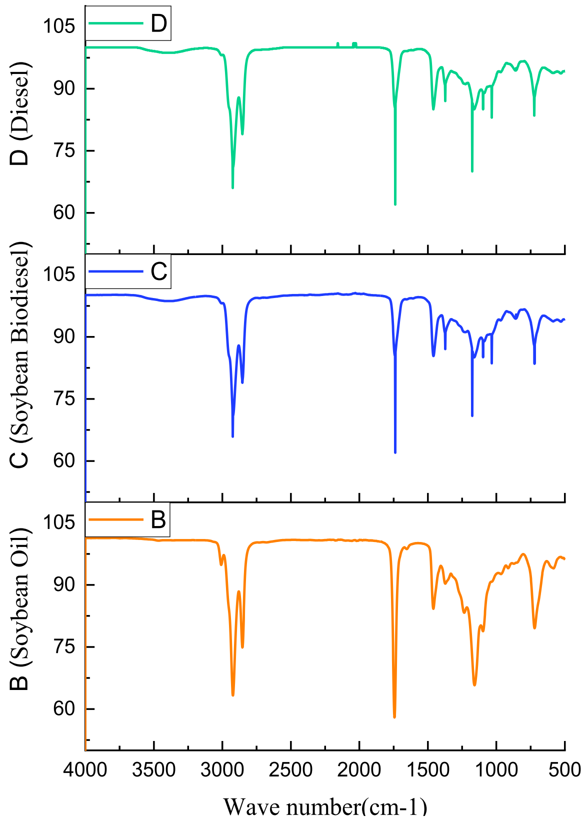

Fig. 8. FTIR of soybean oil (B), (C) biodiesel and (D) diesel.

Table 6
FTIR result of soybean oil, biodiesel and diesel.

Oil			Biodiesel			Diesel		
Frequency range (cm−1)	Bonds	Compounds	Frequency range (cm−1)	Bonds	Compounds	Frequency range (cm−1)	Bonds	Compounds
2925.532	C–H stretching	alkane	2923.46	C–H stretching	alkane	2927.46	C–H stretching	alkane
2856.106	C–H stretching	Alkane	2854.39	C–H stretching	Alkane	2859.963	C–H stretching	alkane
1745.291	C = 0	esters	1736.88	C═O stretching	esters	1463.73	C–H bending	alkane
			1176.09	C–O stretching	esters	730.9	= C–H Bend	alkenes
			1098.16	C–O stretching	esters			
			1034.12	C–O stretching	esters			
			721.8	C–H Rock	alkanes			

1 from the spectrum of the soybean oil clearly confirm the conversion of soybean oil into biodiesel. A similar type of work has been reported by NN Mahamuni et al. [42].

3.2. Oxidative stability test

It demonstrates that compared to the biodiesel blend, the diesel fuel exhibited a higher oxidative stability. Conversely, the blends' IP increased with the addition of antioxidants as additives, indicating better oxidation stability. This is important because oxidation causes deposits to build in the engine, which eventually lower engine performance when utilizing biodiesel blends in diesel engines. To ascertain oxidation stability, the neat ethyl esters' induction time (IP) and their blend with additive were utilized. In compliance with EN 14112, the IP was tested using an 892 Professional Rancimat apparatus. Soybean oil is highly unsaturated fatty acid-containing, which makes it easily oxidize even though it's edible.

The induction period (IP) and change in oxidation time of soybean biodiesel as a function of antioxidant are shown in Fig. 9(A, B). The oxidation stability of pure soybean biodiesel without antioxidant addition is shown in Fig. 9 (A). Biodiesel without additives has a poor stability (4.51 h), which is lower than the EN-14214 and ASTM-D6751 requirements of min 6 and max 3h, respectively. Moringa leaf extract additive, on the other hand, has strengthened the oxidative stability of biodiesel. At concentrations of 1500 ppm, 2500 ppm, 3500 ppm, and 4500 ppm, the Moringa ethanolic extract raised the IP by 77%, 74%, 72%, and 69%, respectively as illustrated in **9** (B). This finding was higher than earlier research, which reported 15.25h at 1500 ppm and 13.49h at 4000 ppm [25,26].

3.3. Effect of additives on engine performance parameters

3.3.1. Effect of additives on brake thermal efficiency (BTE)

Engine performance and fuel economy are evaluated based in large part on brake thermal efficiency, which quantifies the engine's capacity to convert fuel energy into workable effort [43]. Fig. 10 shows the relationship between engine load and brake thermal efficiency. The brake thermal efficiency of B0, B15, B20, B25, B15E2M, B20E2M and B25E2M were found to be 34%, 32.50%, 31.50%, 30.14%, 33.25%, 32% 31% respectively at final load condition. According to the result, BTE was decreasing as the biodiesel in the blend was increasing. the percentage decrement of the blended fuels B15, B20 and B25 were 7.44%, 10.89% and 13.9% respectively.

On the other hand, the BTE of B15E2M, B20E2M and B25E2M increased by 3.54%, 7.46% and 10.56% when compared to that of the blended fuels without additives respectively. The BTE was increased with percentage increment of 4.22%, 3.84% and 3.89% respectively. It has been determined that while biodiesel has a higher viscosity and a lower energy content than diesel fuel, its BTE value is lower. However, because the additives have a lower viscosity and shorten the ignition delay of the blend fuel, the BTE value of soybean biodiesel/diesel with additives was somewhat greater than that of blended fuels without additives under all load circumstances.

3.3.2. Effect of additives on brake specific fuel consumption (BSFC)

The quantity of fuel burned per unit of power that is generated by the engine is measured as BSFC. Lower BSFC values indicate improved fuel economy. Fig. 11 demonstrates the variation of brake specific fuel consumption (BSFC) with engine load. The average BSFC of B0, B15, B20, B25, B15E2M, B20E2M and B25E2M were 0.394, 0.420, 0.440, 0.446, 0.4, 0.421 and 0.431 kg/kwh respectively. On average, the BSFC value of, B15E2M, B15, B20E2M, B25E2M, B20 and B25 was higher than that of pure diesel by 1.6, 6.1, 6.5, 8.7, 10.4, and 11.8 % respectively. This increment in BSFC was due to lower calorific value of biodiesel.

However, in comparison to soybean biodiesel blends without additive, the blended fuels B15E2M, B20E2M, and B25E2M decreased the BSFC by 4.6, 4.1, and 3.4%. This is because the additives have a lower calorific value and are more volatile, which speeds up the air/fuel mixture mixing velocity and improves combustion efficiency. Overall, the results showed that, with a small variation, the BSFC of pure diesel and soybean biodiesel/diesel with additives is comparable to that of pure diesel at all engine loads.

3.3.3. Effect of additives on exhaust gas temperature (EGT)

The engine's burning efficiency can be ascertained by measuring the exhaust gas temperature. The heat of the fuels evaluated throughout the combustion time is shown by the EGT [44]. Fig. 12 shows the exhaust gas temperature (EGT) at different blends and engine loads. EGT rises for all fuels with load. This is because there was too much fuel in the combustion chamber and not enough air to create a suitable air-fuel mixture. The maximum EGT recorded at 80% load for B0, B15E2M, B20E2M, B25E2M, B15, B20 and B25 which is 360, 365, 367, 373, 365, 368, and 375 °C respectively. Thus, B25, B20 and B15 produced about 6.5%, 6.3%, and 2.8% higher EGT in average respectively related to pure diesel. The greater viscosity of biodiesel causes an increase in ignition delay and causes combustion to occur at a later stage, which raises the EGT. The addition of Moringa leaf extract antioxidant and ethanol to B15, B20

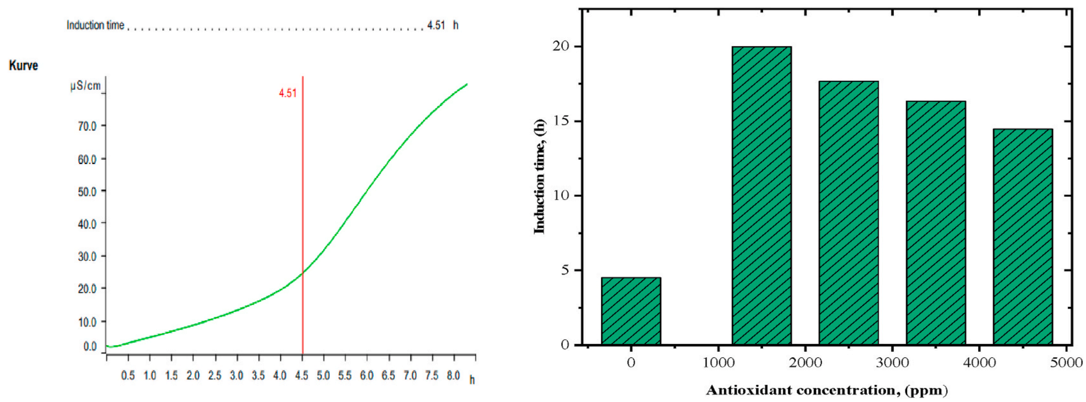

Fig. 9. (A) Induction period (IP) of soybean pure biodiesel and (B) Changes of oxidation induction times of biodiesel as a function of antioxidant concentration.

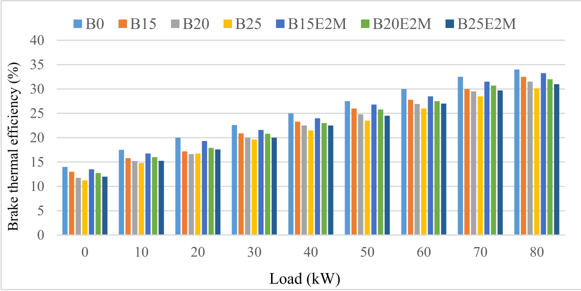

Fig. 10. Brake thermal efficiency at various blends in relation to engine load.

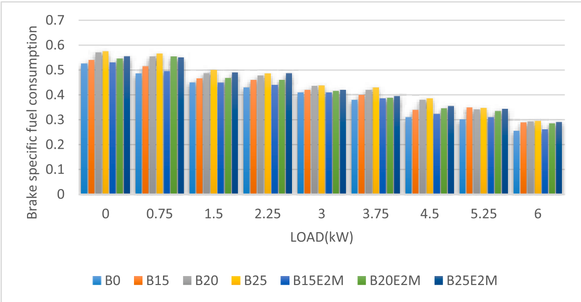

Fig. 11. Brake specific fuel consumption versus engine load at different blends.

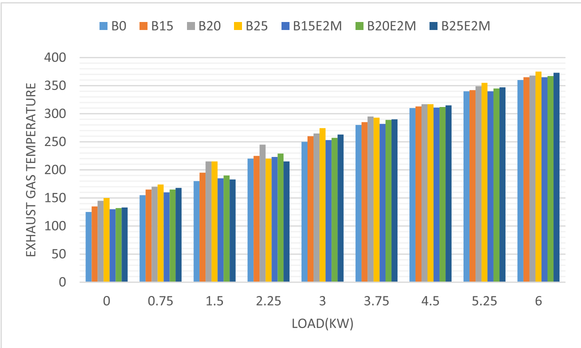

Fig. 12. Exhaust gas temperature versus engine load at different blends.

and B25 were reduced the EGT by 1.6%, 3.5% and 3.6% as compared to B15, B20 and B25 respectively. This result is due to the additive's strong evaporative heat, which remove heat from the area where combustion takes place.

3.3.4. Effect of additives on brake power (BP)

Fig. 13 illustrates the difference in brake power for blends and diesel fuel at varies loads. It is evident that brake power climbed steadily up to a 20% load, at which point it began to decrease. Moreover, power output values decreased as the amount of soybean biodiesel in the blends increased for the full engine loads. The higher BP was collected at this particular load for B0, B15E2M, B15, B20E2M, B25E2M, B20 and B25 were 3.256kw, 3.225kw, 3.170kw, 3.160kw, 3.137kw, 3.125kw, and 3.104 kw respectively. As a result, B15E2M, B15, B20E2M, B25E2M, B20 and B25 produced a lower output power which was reduced by 0.8, 2.0, 3.2, 4.6, 5.6 and 6.9% respectively as compared to diesel. Because of the lower calorific value of biodiesel in comparison to diesel fuel, the maximum produced power in an unmodified diesel engine fueled with biodiesel or its blends is generally lower than that of diesel fuel [45].

Conversely, the inclusion of antioxidant-rich Moringa stenopetala leaf extract and ethanol additions to soybean biodiesel blends increased the blends' brake power by 1.28, 2.52, and 2.54% in comparison to B15, B20, and B25 blends, respectively. This was because the additives reduced the viscosity and density of the blends. Overall, it can be stated that a blend of diesel fuel with low volumetric ratios of biodiesel and additives has power that is nearly identical to pure diesel. This may be because the high oxygen content of the biodiesel and additives improve combustion conditions [46].

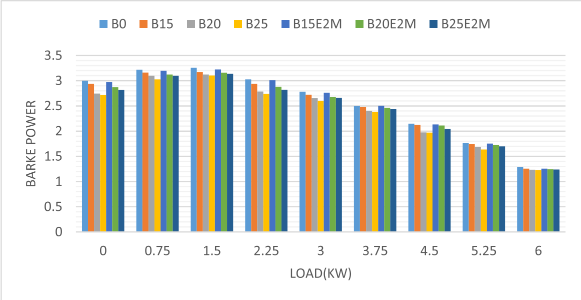

Fig. 13. Brake power versus engine load at different blends.

3.3.5. Effect of additives on brake torque (BT)

The brake torque variation for diesel fuel and blends as a function of engine load is illustrated in Fig. 14. Diesel, B15, B20, B25, B15E2M, B20E2M, and B25E2M all had maximum braking torque values of 12.60, 11.87, 11.73, 11.59, 12.34, 11.95, and 11.88 Nm at a 3.75 kW load, respectively. In comparison to diesel fuel, 2.07, 5.17, 5.72, 5.83, 6.90, and 8.01% at this engine load by the B15E2M, B20E2M, B25E2M, B15, B20, and B25 reduced the brake torque. Additionally, engine torque is decreased when a blend has a larger proportion of biodiesel fuel [47].This decrease is caused by the higher viscosity of biodiesel fuel and its increased oxygen content, which produce fuel-lean areas in the combustion chamber that have positive effects on exhaust gas emissions and lower heating values, which also reduce brake torque [48]. Conversely, 3.35, 1.57, and 1.32% when compared that of soybean biodiesel blends without additives respectively increased the BT of soybean biodiesel blends with additive (B15E2M, B20E2M and B25E2M). This is because the lower viscosity of the biodiesel blends with additive.

3.4. Effect of additives on engine emission characteristics

3.4.1. Effect of additives on Carbon Dioxide (CO_2)

CO_2 emissions of the engine driven by different blends of soybean biodiesel and diesel fuels with ethanol and moringa leaf extract additives is measured at different engine load and the result is depicted in Fig. 15. As per the result, the average CO_2 emissions of B0, B15, B20 and B25 were found to be 4.3, 4.6, 5.0 and 5.4% respectively. As compare to diesel, the blended fuels B15, B20 and B25 increased CO_2 emission with the percentage increment of 7.42%, 18.5% and 27.5% respectively. Moreover, CO_2 emissions of the blended fuels with additives (B15E2M, B20E2M and B25E2M) were 5.0, 5.5 and 5.8% respectively. This implies that CO_2 emissions of the blended fuels with additives further increased by 10.36%, 8.4% and 7.5 % for the respective blends respectively. The increased in CO_2 emissions of the blended fuels were due to the higher oxygen content of the biodiesels and ethanol additive that initiates the combustion to be enhanced thereby it causes CO_2 emissions to be increased [49].

3.4.2. Effect of additives on carbon monoxide (CO)

Inadequate mixing, oxygen deficiency, and fuel-rich areas are the causes of incomplete combustion, which raises CO emissions [50]. Fig. 16 shows the CO emission Changes as a function of engine load. It was found that the average CO emissions for B0, B15, B15E2M, B20, B20E2M, B25, AND B25E2M were 0.452, 0.39, 0.33, 0.31, 0.25, 0.27, and 0.21%. Furthermore, it was noted that, in comparison to the blends, the engine produces a lot more CO for diesel at all load settings. Thus, for B15, B15E2M, B20, B20E2M, B25, and B25E2M, the decrease in CO emissions relative to diesel fuel was 13.45, 27.86, 31.77, 44.43, 41.16, and 53.19%, respectively. This is due the higher oxygen content in biodiesel blends, which leads to increase the cylinder temperature as the percentage of load in the engine increased. This causes to improve the fuel atomization that improves air fuel mixing and thereby enhanced combustion of the

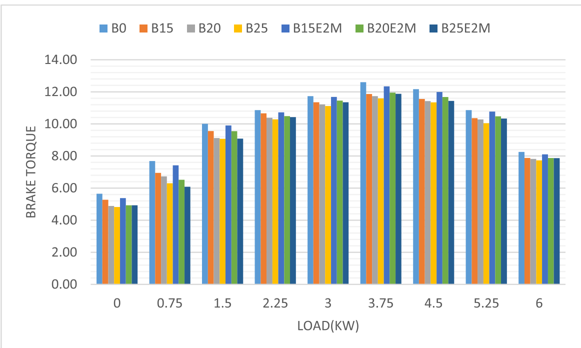

Fig. 14. Brake torque versus engine load at different blends.

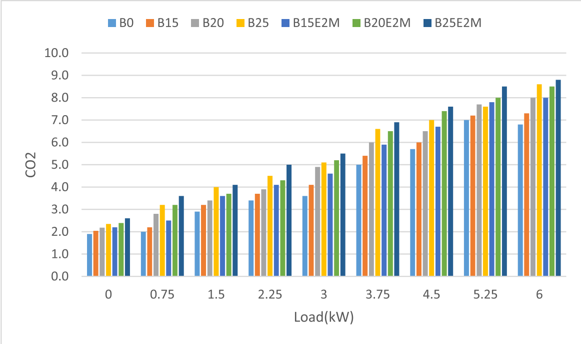

Fig. 15. Carbon Dioxide versus engine load at different blends.

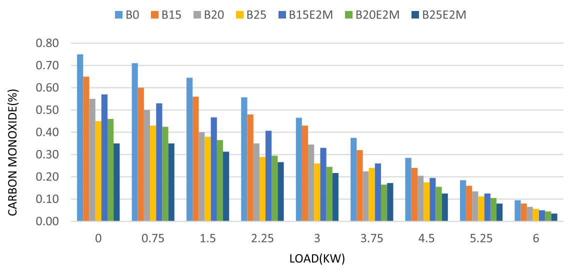

Fig. 16. Carbon monoxide versus engine load at different blends.

diesel engine.as a result the CO emission decreased in biodiesel blends [51,52]. Furthermore, the CO emission was decreased with the addition of ethanol and moringa stenopetela leaf extract additives. Therefore, CO emission of soybean biodiesel blends with additives decreased by 16.65, 18.56 and 20.27 % for B15E2M, B20E2M, and B25E2M as compared to soybean biodiesel blends without additives respectively. This is due to the additives' high hydroxyl group content, which helps the cylinder's hydroxyl group release facilitate the oxidation of CO to CO2, which lowers the quantity of CO produced [53].

3.4.3. Effect of additives on unburned hydrocarbons (UHC)

The hydrocarbon production in the diesel engine is significantly influenced by the fuel's qualities and spray characteristics. The two primary causes of hydrocarbon emissions in diesel engines are under mixing of the fuel and leaner mixing than the combustion limit [54]. Fig. 17 illustrates how the engine load affects the variation in HC emissions for diesel and biodiesel blended fuel. All fuel modes exhibited a decrease in HC emissions as engine load increased. Diesel, B15, B15E2M, B20, B20E2M, B25, and B25E2M had maximum HC emissions of 80, 78, 75, 71, 69, 71, and 66 ppm at no load, respectively. Comparing B15, B20, and B25 to pure biodiesel blends, the reduction in HC was 4%, 3%, and 8%, respectively, with the addition of 1500 ppm leaf extract and 2% ethanol. This is due to biodiesel blends with additives have slightly higher oxygen content than the pure blend and much higher than diesel fuel, which could improve the combustion and lead to lower HC emissions [55].

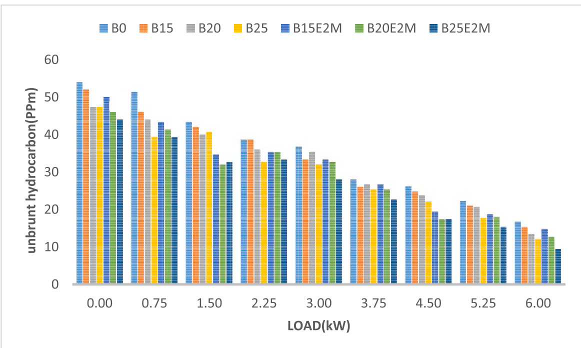

Fig. 17. Unburned hydrocarbons versus engine load at different blends.

3.4.4. Effect of additives on Oxides of Nitrogen (NOx)

An internal combustion engine's ability to create NOx is primarily dependent on the temperature at which the engine burns. As the exhaust temperature rises, more NOx is created during fuel combustion [56]. The temperature at which combustion occurs has a major influence on the production of NOx in internal combustion engines. More NOx is produced during fuel combustion when the exhaust temperature rises [56]. The variation in NOx emissions for the studied fuels at various engine loads is shown in Fig. 18. Regarding load, the NOx emissions for diesel and all blends showed a rising trend. When comparing the blends to diesel, higher emissions were observed at all loads. The average NOx emissions for B15, B20, B25, B15E2M, B20E2M, and B25E2M were determined to be 252, 312, 325, 339, 303, 306, and 315 ppm, respectively. Nevertheless, it was detected that NOx emission for fuel B15E2M, B20E2M, AND B25E2M was lower than blends without additives throughout the entire loads. It was found that B15E2M, B20E2M, AND B25E2M gives average reduction of 3, 6 and 7% respectively as compared to B15, B20 and B25. It can be concluded that 1500 ppm anti-oxidant and 2% ethanol additive are effective to reduce NOx emission Moreover, the low cetane number of ethanol results in a decrease in the residence period available for the formation of NOx, which lengthens the ignition delay [56]. This case is also supported by the lower EGT. Increased latent heat of evaporation from the addition of additives absorbs and lowers the temperature in the combustion chamber, which reduces the amount of NOx emissions [48].

3.5. Strength and weakness of soybean biodiesel blend

The main benefit of soybean biodiesel blend over petroleum-based diesel is that it is non-toxic and biodegradable, which makes it safer for the environment. It burns cleaner and ignites more readily than petroleum-based diesel because it has a higher cetane rating. Compared to petroleum-based diesel, it is more lubricating, which can prolong engine life and lessen wear and tear.

The main drawbacks are that, compared to diesel derived from petroleum, soybean biodiesel has a higher viscosity, which can be problematic during cold weather. Compared to diesel made from petroleum, it contains less energy, which may lead to reduced fuel efficiency. If blended improperly with petroleum-based diesel, it can lead to deposits in engines and clog fuel filters. Production costs may be higher than those of petroleum-based diesel.

4. Conclusion

Price, yield, and environment are some of the factors that affect the extraction process. When selecting an extraction technique, it is essential to consider these parameters in order to guarantee the sustainability and efficiency of soybean biodiesel production. As a result, a mechanical press is used to extract the oil, and the trans esterification process is used to turn it into biodiesel. To assess the oxidative stability of soybean biodiesel, different concentrations of the antioxidant component Moringa were added at 1500, 2500, 3500, and 4500 ppm. On a single-cylinder diesel engine, a biodiesel blend containing the additives Moringa at 1500, 2500, 3500, and 4500 ppm and 2% ethanol were tested. Consequently, the results and discussion section led to the following key conclusions.

- The extracted oil's physical-chemical characteristics and the ensuing FAEE met ASTM and EN requirements. When antioxidants were added to biodiesel, the fuel's oxidation stability rose dramatically—by 77%—when compared to pure biodiesel. However, as the proportion of Moringa antioxidant was increased, the biodiesel blends' oxidation stability decreased.
- The performance characteristics of soybean biodiesel, such as brake power, torque, and thermal efficiency, were enhanced by 6.5% in average with the addition of ethanol and antioxidant compounds from the Moringa leaf, while the fuel consumption specific to the brakes was decreased by 0.421%.
- The addition of ethanol and moringa additives greatly decreased the emission characteristics such as HC, CO, and NOx when compared to pure biodiesel blends, but increased CO2. In general, the physicochemical properties, performance, and emission characteristics of the B15 blend with additive are comparable to those of diesel fuel. Therefore, there is no need to modify the engine.

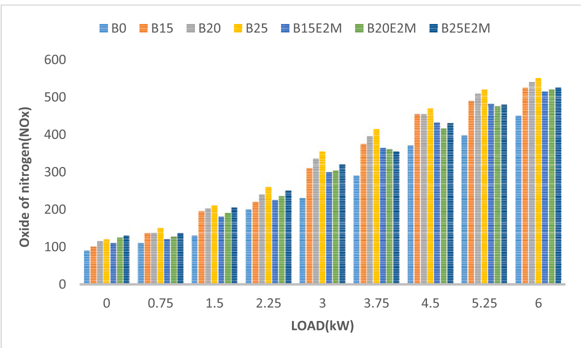

Fig. 18. Oxides of Nitrogen versus engine load at different blends.

Data availability

Material mentioned in the article, added content, or cited in the article.

CRediT authorship contribution statement

Dinku Seyoum Zeleke: Supervision, Conceptualization. **Atsedemariam Ayalew Bezabih:** Investigation, Data curation.

Declaration of competing interest

The authors state that none of their known financial conflicts or interpersonal connections could have influenced the work that was published in this paper.

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