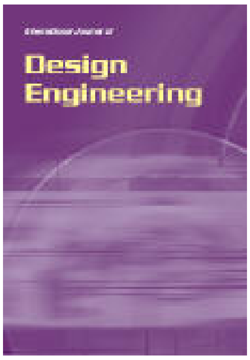

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Comprehensive review of biodiesel as an alternative fuel for diesel engines

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Comprehensive review of biodiesel as an alternative fuel for diesel engines

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Abstract: Diesel engine is a popular prime mover applied worldwide. It is necessary to find an alternative of diesel fuel in order to run diesel engines efficiently, as well as to reduce its prolusion to the environment. Biodiesel is such an alternative, which can be obtained from both edible and non-edible plants and crops, with some chemical processes, biodiesel properties can be modified to use as blends in diesel fuel. Selected biodiesel blends boost brake specific fuel consumption and decrease brake thermal efficiency in comparison to diesel. In most cases, the biodiesel has better results in carbon monoxide and hydro carbon emissions, although high cylinder temperatures also boost nitrogen oxides emissions. This analysis comes to the realisation that these modified biodiesels with better quality can be pumped in a specific proportion into a diesel engine without modifying the engine components. Therefore, the biodiesel is renewable, biodegradable, and non-toxic.

Keywords: diesel; biodiesel; combustion; engine; thermal efficiency; nitrogen oxides.

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1 Introduction

All over the world, diesel engines are widely accepted as an efficient prime mover for various daily applications such as transportation, agricultural, power generation, etc. Global warming and high petroleum costs create an interest in finding out alternative fuels. Diesel engines have a serious concern about oxides of nitrogen (NO_x) as well as particulate matter. For better utilisation of diesel engines, seriously concern matter is to reduce emission values to an acceptable level. Various types of vegetable oils should be an alternative option for solving this issue. A detailed study on various alternative fuels proved that biodiesel is a good option for diesel engines, which requires almost no modification in engine construction. But cold flow properties and poor storage stability are drawbacks of biodiesel, but they may be overcome by the use of alternative materials (Misra and Murthy, 2011).

Vegetable oil is a form of triglycerides, very useful for conversion as biodiesel. Biodiesel is rich in oxygen content. After a chemical process, it has the same energy content as diesel fuel, making it a good choice as an alternative fuel (Koh and Tinia, 2011). Vegetable oil reduces sulphur oxides, poly aromatic hydrocarbons, noise and particulate matter during combustion in diesel engines (Murayama, 1994). Uses of vegetable oils directly are not practically acceptable as fuel due to improper combustion properties. For utilisation of vegetable oil in a diesel engine, a transesterification process is required to convert it into fatty acid methyl ester and also required to reduce viscosity for proper fuel atomisation (Sendzikiene et al., 2006).

Biodiesel is a monoalkyl ester with a long fatty acid chain. Biodiesel is made from both edible and non-edible types of vegetable oils. In comparison to conventional fuel, biodiesel is non-toxic and biodegradable. Biodiesel contains no petroleum products. Biodiesel has the ability to blend with diesel and work as a fossil fuel.

Experiments on vegetable oils have been carried out since a long time back. The first experiment was carried out using peanut oil by Rudolf Diesel. Many researchers have been working on various biodiesels to check the feasibility of those alternates as diesel engine fuel. As a result, a thorough examination of the various types of biodiesel, their properties, and behaviour as an alternative fuel to diesel is required.

2 Review of biodiesel performance

The biodiesel can be produced from many types of vegetable oils. This literature review covers some of the biodiesel which is easily available as an option to use in diesel engines as fuel. The properties of some of the biodiesel are shown in Table 1.

Table 1 Fuel/biodiesel properties

Fuel type	*Viscosity at 40°C (cSt)*	*Calorific value (MJ/kg)*	*Cetane number*	*Specific gravity*
Diesel (Leung et al., 2010)	3.522	43	47	0.815
Castor (Panwar et al., 2010)	10.5	39.16	–	0.913
Croton megalocarpus (Aliyu et al., 2011)	4.8	40.28	40	0.904
Jatropha curcas (Leung et al., 2010)	4.78	40–42	61–63	0.8636
Jojoba (Saleh, 2009)	19.2	47.38	63.5	0.866
Mahua (Arumugham et al., 2012)	3.96	37.2	–	0.88
Palm (Leung et al., 2010)	4.42	34	62	0.86–0.9
Pine oil (Vallinayagam et al., 2013)	1.3	42.8	11	0.875
Pongaminapinnata (Leung et al., 2010)	4.8	42	60–61	0.883
Rapeseed (Leung et al., 2010)	4.3–5.83	45	49–50	0.88–0.888

2.1 Jatropha oil methyl ester

Jatropha is a species from which biodiesel can be produced. Its cake is also used as feed for fish and other animals. Jatropha has a rich oil content (Mofijur et al., 2012). Jatropha curcas has many benefits, such as:

1. it can grow on any type of land
2. easy propagation
3. it is capable of working as windbreak due to stabilising sand dunes
4. there is no need for fertilisers to grow
5. glycerin is a byproduct that is both useful and profitable
6. capable of completely recycling CO_2 emissions
7. oil is used in the soap industry due to high saponification
8. The oil can burn without producing smoke (Hossain and Davies, 2010; Rahman et al., 2010).

Jatropha seeds have higher fatty acid content, which is the main issue. JOME has a low acidity, a low viscosity, and good cold properties. When compared to diesel fuel, jatropha biodiesel has higher density, fire, and flash point values (Tamilselvan et al., 2017). The National Biodiesel Board of India accepted JOME as a blend fuel for diesel engines as commercial engine fuel.

In the normal way, due to the high viscosity of jatropha oil, it is not advisable to inject directly into the engine. For using this oil, one has to heat it or make a blend of jatropha oil with diesel in the proper proportion. In the case of preheated jatropha oil, due to its lower viscosity, thermal efficiency is increased compared to unheated jatropha oil (Chauhan et al., 2012).

Agarwal and Agarwal (2007) tested different blends of jatropha oil with diesel fuel in a diesel engine, which is commonly used in the agricultural sector. BTE was reduced when jatropha blends were used. However, up to 20% blends, it was nearly as good as diesel. With preheating and blending in fuel, he discovered a higher BSFC than diesel fuel. When compared to diesel fuel, JOME emits more CO, CO_2, and HC. With the preheating of JOME (Hossain et al., 2013), this emission was reduced.

During the test run, it was discovered that the engine produces less torque and power than diesel by El-Kasaby and Nemit-Allah (2013). This is due to lower calorific value and higher fuel consumption. Because of the higher cetane number and oxygen content, complete combustion occurs, resulting in lower CO emissions (Jain and Sharma, 2010). JOME use in diesel engines lowers torque, BTE, PM and smoke emissions (Sangeeta et al., 2014).

Roy et al. (2021) performed experiments on a single cylinder water cooled computerised test rig to analyse the effect of castor jatropha biodiesel blends on CI engine. They used 10% of jatropha and 10% of castor biodiesel with blends of base diesel fuel with a concentration of water particles. The result shows a 15% increment in BTE and a 16.7% increment in BSFC at 5% addition of water in blends. At this concentration of water, CO_2 was recorded at its maximum due to complete combustion, whereas CO emissions were 60% compared to diesel fuel. Due to the addition of water, the oxygenated content of fuel increases, which reduces NO_x emissions.

Dubey and Gupta (2018) used a mixture of high viscosity jatropha biodiesel and low viscosity turpentine oil with different concentrations to evaluate engine performance. The density and viscosity of jatropha biodiesel were increased with the increment of turpentine oil in jatropha oil. They selected a single cylinder direct injection diesel engine to evaluate engine performance. They found smooth operation of the engine up to the addition of 50% jatropha biodiesel in the dual bio fuel mixture. At a 50% blend of jatropha biodiesel in dual bio fuel mixture, BTE was reported to be higher and there was a decrease in exhaust emissions such as CO, HC and NO_x. This research demonstrates the option to use jatropha biodiesel in a mixture with turpentine oil as an alternative fuel.

To evaluate the impact on diesel engine performance, Patel et al. (2017) used 0 to 5% DEE additives with a 20% concentration of jatropha biodiesel in diesel fuel. They discovered that adding DEE additives at a rate of 4% to a combination of 20% jatropha produces better results for reducing HC and NO_x.

Due to its high cetane number, jatropa oil is a good alternative, which does not require any engine modification. Preheating or less blending of JOME at higher injection pressure and higher CR is a suitable option for diesel engines.

2.2 Cottonseed oil methyl ester

Gossypium hirsutum and *Gossypium herbaceum* are the main species of cottonseed oil. Kernal consist of oil, used in food products. Cotton seed biodiesel is prepared by using a catalyst having 30% methanol and 2% potassium hydroxide.

Augustine et al. (2012) performed a trial run on a single cylinder direct injection type diesel engine with preheat of CSOME at different temperatures. Because biodiesel has a higher viscosity, BSFC is increased for all load conditions. But in the case of preheated CSOME, reduced viscosity and improved spray formation result in higher BSFC and lower BTE. By preheating the fuel, CO, HC and smoke density are less than those of diesel. Due to pre heating, the cylinder temperature increases. This increases NO_x emission. At an 80°C preheat of the blend, CO and HC emissions are reduced compared to diesel fuel (Roy et al., 2013).

Pullen and Saeed (2014) found that in CSOME blends, engine power and torque are slightly lower, whereas BSFC is higher than diesel fuel at higher engine speeds. Daho et al. (2013) found during practical that SFC increased with an increasing volume of CSO in the blend. Mwangi et al. (2015) found that preheating COME up to 90°C can improve combustion and spray formation, resulting in lower CO emissions and higher BTE.

To ascertain the impact of CSO blending in diesel engines, Santhosh and Padmanaban (2016) used naturally aspirated, single cylinder, four stroke diesel engines with varied compression ratios. They came to the conclusion that because of mixed fuel has a lower heating value, more fuel is used, which increased BTE. They observed an increase in BTE of 12.2% at a cottonseed oil blend of 15% with a change in CR from 18 to 21. Higher CR shown to result in a relative drop in BSFC. With the same blend ratio and 21:1 CR, mechanical efficiency and BP increases. Furthermore, they discovered that at 21:1 CR, NO_x emission reduce when compared to diesel at a 15% blend. The results of the experiment cpnclude that using 15% cottonseed oil methyl ester in diesel fuel with a 22 CR in a diesel engine can be used as a substitute for conventional fuel.

Thaniyarasu et al. (2018), in their work, selected esters of linseed and CSO have been blended with diesel at different ratio, and the resulting blended samples have been tested in a single cylinder, four-stroke, diesel engine. The following conclusions are drawn from these samples. Linseed and cottonseed oil mixes up to 2.5% in diesel demonstrate improved engine performance and slightly higher emissions. Diesel emissions of HC, CO and smoke intensity are decreased with 7.5% of linseed and cottonseed oil blends are being used. NO_x emissions were also lower than with a clean diesel operation at the same period. Overall, they discovered that mixing 5% of each type of biodiesel with 90% diesel worked well in every situation for performance, combustion, and emission at maximum loads.

Various experimental results show that B5 and B20 blends can be used with diesel fuel, which does not require any engine modifications. By adjusting injection timing, injection pressure, and CR on the existing diesel engine, more biodiesel can be injected (Bari, 2014).

2.3 Mahua oil biodiesel

Mahua oil is used in soap making. It is non-edible oil. Arumugham et al. (2012) investigated that, at full load, BTE is decreased and SFC is increasing at all blends. At a higher load, CO_2 emissions are more than diesel fuel. CO_2 emissions increase, whereas HC emissions decrease at all loads. NO_x emissions are also increasing for biodiesel blends. The temperature of exhaust gas is lower compared to diesel fuel.

The fuel pump delivers fuel to cylinder on a volume basis. As the density of blends is higher, more mass of fuel is injected per stroke. Puhan et al. (2005) observed more discharge of MOEE causes more BSFC. Due to high cetane no and oxygen content, combustion takes place properly, resulting HC and CO being reduced, but CO_2 being increased.

Raheman and Ghadge (2007) reported a reduction in HC and CO emissions, but an increment in NO_x with an increment of biodiesel in blends. The oxygen content in fuel is high at higher percentages of blends, resulting in complete combustion and high cylinder temperature.

Godiganur et al. (2009) performed practical and conclude, as the heating value of blends is lower, the amount of fuel required for power generation increases, which in turn increases BSFC. He discovered that using a B20 blend maximised BTE. With an increment in blend percentage, exhaust temperature is also increasing. He concludes from his experiments that up to 20% blending of MOEE can be used safely with diesel in heavy duty engine as it does not affect the engine performance and pollution.

Sankaranarayanan and Pugazhvadivu (2012) performed experiments on mahua oil as a base fuel with the addition of hydrogen enriched air as a variable to determine the effect on engine performance. They adopted a single-cylinder diesel engine with a dual fuel delivery system. Gas flow regulation setup was installed to regulate the hydrogen enrichment air injection. After analysing the results, they observed that engine sound intensity increased with the addition of hydrogen, and BTE was at its peak at 40 lpm of hydrogen injection. Second, smoke density is significantly decreased at 40 lpm. Other studies come to the fact that the optimal blends for all parameters involve the injection of 40 lpm of mahua oil.

2.4 Karanja oil biodiesel

The Karanja tree has a kidney-shaped red kernel having approx. 30% oil content. Karanja is rich in nitrogen, potash, and phosphorous and serves a good fertiliser.

Sureshkumar et al. (2008) proved in their experiment that minimum CO is generated at B20 blends, which converts to negligible at B40 and B60 blends. Rao et al. (2008) found at different load conditions, up to B40 blends, HC, CO, and smoke are less compared to diesel fuel.

Agarwal and Dhar (2013) performed experiments on a diesel engine for constant injection pressure with various amounts of karanja oil blends. He found BSFC is increasing with an increasing amount of karanja oil in diesel. As the calorific value of karanja oil is less than diesel, the amount of karanja oil is more in blends, which lowers the calorific value of blends. Therefore, BSFC has increased. Due to poor fuel atomisation, thermal efficiency is observed to be less than diesel fuel (Kumar et al., 2013).

Chauhan et al. (2013) conducted trial runs for all test fuel blends and discovered that CO emission increases with higher loads. At high load, the mixture is rich in nature, which creates incomplete combustion. Using karanja methyl ester blends, unburned hydrocarbons are less than diesel fuel. At high loads, as less oxygen is available to more fuel, UBHC increases.

For comparative study of engine performance, Shrivastava et al. (2019) used different blends of karanja and Roselle biodiesel. As a result, they got 1.5% higher BTE compared to diesel. CO_2 emissions were higher and NO_x emissions were lower than diesel fuel. Their results also proved that 20% blending of karanja is a good option for diesel fuel.

2.5 Castor seed oil biodiesel

It is obtained from *Ricinus communis* plant. These seeds are rich in triglycerides. Caster seeds are also used as lubricants and medicine.

Conducting experiments by Panwar et al. (2010) revealed that BSFC is reduced up to B10 blends and BTE is increasing up to B5 blends. For all load conditions, BSFC at B10 blends is less than diesel fuel. With increment of biodiesel in diesel, due to less calorific value of caster seed oil, overall calorific value of blends is reduced. BTE is decreased and BSFC is increased. Also, the increment in blends results in higher exhaust gas temperature and NO_x. During the measurement of BP, he found maximum BP was at B10 blend.

The torque and engine power generated are less than diesel fuel. Due to low calorific value and higher density, BSFC increases and BTE decreases. Also reported decrement in CO and HC, but an increment in NO_x (Shojaeefard et al., 2013).

2.6 Rapeseed oil biodiesel

Rapeseed oil is a member of the Brassicaceae and is consumed as vegetable oil in South Africa and China.

When compared to diesel fuel, the heating value of rapeseed methyl ester is approximately 2.3% lower. There is a greater mass of fuel required for power generation compared to diesel fuel. This increases the BSFC of ROME. Hazar and Aydin (2010) preheat the rapeseed oil and perform the practical. They found the BTE of preheat blends was less compared to un-preheated rapeseed oil. In preheat oil blend, smoke density and CO emissions are also reduced (Çelikten et al., 2012).

As biodiesel is an oxygenated fuel, it has approx. 10% oxygen content. This reduces CO emissions. During combustion, fuel oxidation improves, resulting in a higher temperature. Even though there is a higher cetane number, due to the high combustion temperature, the generation of NO_x emissions is greater (Tsolakis et al., 2007).

Raman et al. (2019) carried out an experiment to analyse the engine performance using rapeseed oil biodiesel blend with diesel on a single cylinder, four stroke direct injection diesel engine. They found lower BTE with different blends, but at a 20% concentration of blend, a marginal difference was recorded in BTE. BSFC was found to be reduced with neat biodiesel and its concentrations. Exhaust emission such as CO and HC values are lower, whereas smoke and NO_x values are higher compared to diesel fuel. Experimental results conclude that a partial requirement of diesel can be replaced by rapeseed oil biodiesel.

2.7 Palm oil biodiesel

The species of palm oil is commonly known as African oil palm. Due to the lower heating value of palm oil (14.7%) compared to diesel fuel, BSFC of palm oil is observed to be high, whereas BTE is observed to be less compared to diesel fuel. At higher engine speeds, residence time for conversion of chemical energy to heat energy is less, which reduces the BTE of palm oil blends. Also, the emission of CO is less than diesel fuel using palm oil when the engine runs at full load (Chong et al., 2015).

Ozsezen and Canakci (2011) investigated that engine power was reduced and BSFC increased with WPOME as the density of WPOME is 4.17% higher than diesel fuel. For any amount of power generation, more fuel is consumed, which increases BSFC.

Giakoumis et al. (2016) also found there to be a reduction in CO emissions. The operating condition of the engine and the type of fuel are mainly responsible for NO_x generation. NO_x emissions are increased compared to diesel. For more than 50% of the blends, smoke and HC emissions are found to be higher.

Bari and Hossain (2019) used a single cylinder, air-cooled, 5-kW capacity diesel engine to evaluate the effects of palm oil ethyl ester. Because of low calorific value of palm oil biodiesel, fuel consumption is higher, which directly increases BSFC. Due to the presence of oxygenated content in biodiesel, combustion is better, which generates higher temperatures and relatively higher NO_x. Due to oxygen molecules in the mixture, CO and HC emissions are reported to be less than diesel fuel.

Prabu et al. (2018) performed experiments using a stationary four stroke, single cylinder natural aspirated, water cooled direct injection diesel engine with preheated palm oil with a concentration of 20%, 30% and 40% in blend with diesel. The conclusion of these experiments reveals that the BSFC of PO20 + butylated hydroxyl toluene (BHT) is increased and BTE is decreased. The heat release rate of PO20 + n-butanol blends is higher, which increases NO_x emissions. CO emissions are lower than diesel fuel because of the more volatile nature of n-butanol due to its low density. The results proved that these 20% blend of palm oil with additives are a good option for an alternative fuel.

Devarajan et al. (2018) ran an experiment on a 2-cylinder water cooled engine using palm oil blend in a diesel engine. They used silver oxide (Ag_2O) as an additive in diesel blends at 5 to 10 ppm to achieve good combustion, performance, and emission results. They found a good improvement in BTE and a reduction in BSFC compared to normal blends. There were benefits in smoke, HC, CO, and NO_x value as compared to diesel blends. They proved that with the use of silver oxide (Ag2O) as an additive, one can get better results using palm oil biodiesel with diesel blends.

2.8 Pine oil biodiesel

Pine oil is obtained from cones, twigs, and stems of *Pinus sylvestris*. Pine oil trees generally grow in Eurasia in large volumes. Pine oil biofuel has a lower flash point and viscosity, and its calorific value is comparable to diesel fuel.

Vallinayagam et al. (2013) observed during his engine trial run that due to lower viscosity, the heat release rate is higher. Due to better atomisation and evaporation, BSFC is less and BTE is more than diesel fuel. He proved with an experiment that due to pine oil's unique properties, it is suitable for usage as diesel fuel without any chemical processes. Pure pine oil shows better performance compared to diesel fuel.

Tamilselvan and Nallusamy (2015) studied the use of pine oil as an alternative fuel and conducted experiments on a diesel engine having a single cylinder with fix speed. For all combinations of blends, BSFC is lower and EGT is higher. HRR is also higher than diesel. For all conditions, CO and HC are reduced, whereas NO_x is increased by up to 25% with the usage of pine oil (Vallinayagam et al., 2014).

As the quantity of palm oil increases in blends, HC, CO, and smoke intensity decrease. An experiment proved that a diesel engine can run at 100% pine oil without any change in the engine (Tse et al., 2015), which also decreases the exhaust emissions.

2.9 Croton seed oil biodiesel

A croton seed belongs to Euphorbiaceae family, generally used to flavour food and medicine purpose.

Aliyu et al. (2011) performed a trial on a 3-cylinder engine using neat CME. He found higher BSFC and lower BTE than diesel fuel. At 100% of CME, CO emissions are lower at low speed engine operation. But gradually increases with an increase in load on the engine. Fuel consumption for all CME blends is high at low speeds, but at high speeds it decreases.

Table 2 A brief summary of experiments performed by investigators on various types of biodiesel blends

Investigators	*Blend type*	*Engine detail*	*Test parameters*	*Performance observation*	*Emission observation*
Paul et al. (2014)	Jatropha biodiesel	Double cylinder, 4 stroke, water cooled	Varying load, fix speed @ 1,500 rpm	BSFC increases and BTE decreases	With the addition of biodiesel, NO_x and CO_2 increase.
Agarwal and Agarwal (2007)	Jatropha oil	Single cylinder, 4 stroke, water cooled, com ratio: 17.5	Varying load, fix speed @ 1,500 rpm	BSFC and EGT increase, thermal efficiency decreases	With preheat blends, CO, CO_2, and HC are nearly equal to diesel fuel.
El-Kasaby and Nemit-Allah (2013)	Jatropha oil biodiesel	Single cylinder, 4 stroke, water cooled, com ratio:18	Flexible speed range 1,000–2,000 rpm	Torque, power, EGT and BTE decrease, BSFC increases	At high amounts of biodiesel, CO reduce and NO_x increase
Dubey and Gupta (2018)	Jatropha oil biodiesel with turpentine oil	Single cylinder, 4 stroke, water cooled, variable com. ratio	Varying CR, fix speed 1,500 rpm	BTE decrease at more than 50% blend, BSFC increases	CO, HC, NO_x decrease and CO_2 increase
Augustine et al. (2012)	Preheated cottonseed oil methyl ester	Single cylinder, 4 stroke, water cooled, com ratio: 17.5:1	Varying load, fix speed @ 1,500 rpm	BTE decreases, BSFC increases	At 80% CSOME blend, CO and HC decrease whereas NO_x increases
Pullen and Saeed (2014)	Cottonseed oil methyl ester	Single cylinder, 4 stroke, air cooled, com ratio: 18/1	Flexible speed range 1,250–2,500 rpm	Engine torque increase for B5, BSFC increase. EGT decreases	Addition of CSOME decreases CO and NO_x
Daho et al. (2013)	Cottonseed oil	Single cylinder, 4 stroke, air cooled, com ratio: 18:1	Varying load, fix speed @ 2,500 rpm	BSFC and thermal efficiency increase	CO increases, NO_x decrease but CO_2 is same
Santhosh and Padmanaban (2016)	Cottonseed oil methyl ester	Variable CR, single cylinder, 4 stroke, multi fuel	Varying CR, fix speed @ 1,440 rpm	BP and BTE increases at higher CR	HC and CO decreases, NO_x increases
Arumugham et al. (2012)	Mahua oil methyl ester	Single cylinder, 4 stroke, water cooled, com ratio:17.5:1	Varying load, fix speed @ 1,500 rpm	BSFC increases, BTE and EGT decrease	CO, CO_2 and NO_x increase and HC decreases
Puhan et al. (2005)	Mahua oil ethyl ester	Single cylinder, 4 stroke, water cooled, com ratio: 16.5:1	Varying BMEP, fix speed @ 1,500 rpm	BSFC and EGT increase	CO, HC and NO_x decrease but CO_2 increases
Godiganur et al. (2009)	Methyl ester mahua oil	Six cylinder, water cooled, com ratio: 17.6:1	Varying load, fix speed @ 1,500 rpm	BSFC increases, BTE decreases (except B20)	CO and HC reduce whereas NO_x increases

Table 2 A brief summary of experiments performed by investigators on various types of biodiesel blends (continued)

Investigators	*Blend type*	*Engine detail*	*Test parameters*	*Performance observation*	*Emission observation*
Sankaranarayanan and Pugazhvadivu (2012)	Mahua oil with hydrogen enriched air	Single cylinder, 4 stroke, water cooled	Fix speed with hydrogen flow control	BTE increases	Smoke density reduce, NO_x increases
Sureshkumar et al. (2008)	Pongamiapinnata methyl ester	Single cylinder, 4 stroke, water cooled, com ratio: 16.5:1,	Varying load, fix speed @ 1,500 rpm	BSEC and EGT decrease	CO_2, CO and HC decrease
Agarwal and Dhar (2013)	Karanja oil	Single cylinder, 4 stroke, water cooled, com ratio: 17.5:1,	Varying load, fix speed @ 1,500 rpm	BSFC and EGT increase, thermal efficiency decreases	For up to k50, HC and smoke emissions decreases, NO and CO_2 increase
Shrivastava et al. (2019)	Karanja and roselle oil	Single cylinder, 4 stroke, water cooled	Varying load, fix speed @ 1,500 rpm	BTE increases	CO_2 increases, NO_x decreases
Panwar et al. (2010)	Castor methyl ester	Single cylinder, 4 stroke, water cooled, variable CR	Varying load, fix speed @ 1,500 rpm	BTE increases	NO_x remains same at low load, increases at higher load
Raman et al. (2019)	Rapeseed oil	Single cylinder, 4 stroke, water cooled		BTE decreases, BSFC and EGT increase	CO and UBHC decrease, NO_x increases
Ozsezen and Canakci (2011)	Canola and waste palm oil methyl esters	6-cylinder, 4 stroke, water cooled, com ratio:15.9:1	Flexible speed range 1,000–2,000 rpm	BSFC increases	Unburned HC, CO, CO_2 reduce
Bari and Hossain (2019)	Palm oil ethyl ester	Single cylinder, air cooled	Varying speed	BSFC increases	CO and HC decrease, NO_x increase
Vallinayagam et al. (2013)	Pine oil	Single cylinder, 4 stroke, water cooled, com ratio: 17.5:1,	Varying load, fix speed @ 1,500 rpm	BSFC decreases, BTE increases	At 100% blend pine oil, CO, HC and smoke reduce, NO_x increases
Tamilselvan and Nallusamy (2015)	Pine oil	Single cylinder, 4 stroke, air cooled, com ratio: 17.5:1,	Fix speed @ 1,500 rpm	BTE and EGT increase, BSFC decreases	CO and HC decrease, CO_2 and NO_x decrease
Aliyu et al. (2011)	*Croton megalocarpus* methyl ester	3-cylinder, 4 stroke, water cooled, com ratio: 18.5:1,	Flexible speed range 500–2,200 rpm	BSFC and EGT increase, BTE decreases	CO, CO_2 and HC increase, smoke emission decreases
Kivevele et al. (2011)	Croton oil methyl ester	Four cylinder turbo charged diesel engine	Varying load, fix speed	BTE and BSFC decrease	CO and NO_x slightly increase
Saleh (2009)	Jojoba methyl ester	2-cylinder, 4 stroke, water cooled, EGR, com ratio: 16.4	Flexible speed range 1,000–1,900 rpm	BTE and EGT increase, BSFC decreases	CO, HC and NO_x increase

Wu et al. (2013) conclude that if CMO is heated to 90°C before injection, it results in higher efficiency and particulate emission of the diesel fuel. Due to the lower calorific value of CMO compared to diesel, higher SFC is recorded at all load conditions compared to diesel fuel. Due to increment of CMO in diesel blend, calorific value of blend mixture reduced, which increases BSFC.

Kivevele et al. (2011) also conclude that BSFC is lower (14.24%) for diesel fuel compared to 100% blends of CMO. Also, emissions of NO_x and CO were measured a little higher with biodiesel fuel blends. Due to high viscosity, fuel atomisation is poor, which increases CO emissions. At lower speeds, CO and NO_x emissions are less but increase with an increment in engine speed.

2.10 Jojoba oil biodiesel

Jojoba belongs to the Simmondsiaceae family. The seed contains 50% of the oil quantity by weight. The refined oil is used for several cosmetic products.

Saleh (2009) found results in their experiments that BSFC decreased and BTE increased at all test conditions. BTE and engine power is slightly more than diesel fuel at low speeds. Due to less calorific value, the BSFC of JME is lower by 8.2% at higher speed (1,600 rpm). At higher engine speeds, NO_x and HC emissions increase whereas CO decreases (Kumar et al., 2016). With use of EGR at a rate of (5–15%), better trends in HC, CO and NO_x can be achieved (Saleh, 2009).

3 Conclusions

There are different types of vegetable oils available all over the world having good properties for behaving as alternative fuels for diesel engines with some chemical processes. According the review of selected types of biodiesel presented in this paper, the following conclusion is derived:

1. Biodiesel produced from vegetable oils has a low calorific value and somewhat higher viscosity compared to diesel fuel. By reducing the viscosity of biodiesel with alternative methods, biodiesel blends can be injected directly into engines as fuel.
2. The biodiesel calorific value is less than diesel, resulting in a higher BSFC compared to diesel fuel, which can be optimised with the cost of blended fuel.
3. As HRR is lower due to the low calorific value of biodiesel, the BTE of the blend is less than diesel fuel.
4. As biodiesel has higher oxygen content, combustion can be improved, which result in lower CO and HC emissions.
5. Due to the high oxygen content present in biodiesel, more oxygen is available for combustion, which creates a high temperature in the cylinder, resulting in increased NO_x emissions.

Looking at all the investigators' research and reviews, we can conclude that biodiesel can be used with an optimised amount of blends in diesel engines without any modification.

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Abbreviations

BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CME	Croton seed methyl ester
CO	Carbon monoxide
CO_2	Carbon dioxide
CSO	Croton seed oil
CSOME	Croton seed methyl ester
DEE	Di ethyl ether
EGT	Exhaust gas temperature
HC	Hydro carbon

HRR	Heat release rate
JME	Jojoba methyl ester
JOME	Jatropha oil methyl ester
NOx	Nitrogen oxides
RO ME	Rapeseed oil methyl ester
SFC	Specific fuel consumption
UBHC	Un-burnt hydro carbon.