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Yellow Oleander (*Thevetia peruviana*) Seed Oil Biodiesel as an Alternative and Renewable Fuel for Diesel Engines: A Review

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Abstract: Biodiesel, an alternative and renewable fuel for diesel engines, consists of alkyl esters of long chain fatty acids, more commonly methyl esters and is typically made from nontoxic, biological resources such as edible and non-edible vegetable oils, animal fats, waste cooking oils and oil from algae by transesterification with methanol. Despite many processes of biodiesel production, transesterification method is successfully employed to reduce the high viscosity of triglycerides and improve other characteristics of biodiesel fuel. Biodiesel has been chosen as one of the interesting alternative fuels and has been receiving a lot of attention throughout the world as it is renewable, biodegradable, non-toxic and environment-friendly fuel. Currently, it is economically not feasible to use food-grade vegetable oils to produce biodiesel because of the food shortage and day to day increase in feedstocks price. Much attention has been devoted to the application of low cost non-conventional and non-edible feedstocks from the wild plants to produce biodiesel. Plants bearing non-edible seeds have the potentials of reclaiming wasteland and do not compete with food crops and utilization of these non-conventional and non-edible feedstocks can be sustainable for biodiesel production. This paper is an attempt to review on production, fuel properties and blending effect of biodiesel from yellow oleander (*Thevetia peruviana*) seed oil, a non-edible feedstock having 60–65% oil content.
Key words: Biodiesel, transesterification, *Thevetia peruviana*, fuel properties, yellow oleander.

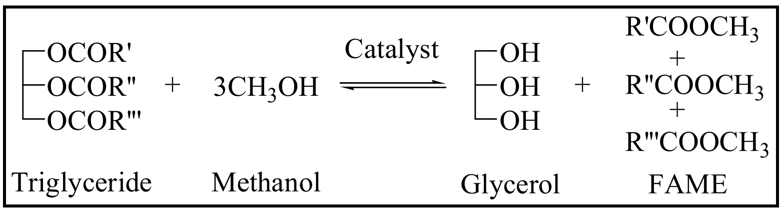
Introduction

Due to rapid population growth and economic development, the worldwide energy demand is constantly increasing. The energy demand is fulfilled mainly from the conventional energy resources like coal, petroleum and natural gas. But, the petroleum reserves concentrated in certain regions of the world are fast depleting day by day and at the current usage rate, these sources will soon be exhausted. Recently, due to the shortage of fossil fuels throughout the world, crude oil price increase and contribution of these fuels to pollute the environment, biodiesel is being attracting increasing attention worldwide as a potential alternative and renewable fuel for diesel engines[1-4].

Biodiesel, an alternative and renewable fuel for diesel engines, consists of mono-alkyl esters of long chain fatty acids, more commonly methyl esters and is typically made from nontoxic, biological resources such as edible and non-edible vegetable oils, animal fats, waste cooking oils and oil from algae by transesterification with methanol[5-8]. Biodiesel has been chosen as one of the interesting alternative fuels and has been receiving a lot of attention throughout the world as it is renewable, biodegradable, non-toxic and environment-friendly fuel[9-11]. Biodiesel produces lower emissions, possesses high flash point, better lubrication, and high cetane number and has very close physical and chemical characteristics to those of conventional diesel fuel allowing its use either on its own (pure biodiesel, B100) or mixed with petroleum based diesel fuel (preferred ratio 5–20%, B5–B20) with very few technical adjustments or no modification[12-15]. Burning of biodiesel fuel does not contribute to a rise in the level of carbon dioxide in the atmosphere and consequently to the green house effect. The biodiesel produced from the renewable resources could help to minimize the fossil fuel burning and CO_2 production. Biofuels and bioproducts produced from plant biomass mitigate global warming. This may be due to the CO_2 released in burning equals the CO_2 tied up by the plant during photosynthesis and does not increase the net CO_2 in the atmosphere[16].

The concept of biodiesel as an engine fuel dates back to 1895 when Dr. Rudolf Diesel (1858-1913) developed the first diesel engine with the intention to run on vegetable oils[17]. He used peanut vegetable oil to demonstrate first its invention at the World Exhibition in Paris in the year 1900. In 1912, Diesel said, “The use of vegetable oils as engine fuel may seem insignificant today. But such oils may, in the course of time, become as important as petroleum and coal tar products of the present time.” This prophetic statement of Rudolf Diesel is a reality now. It is known that petroleum is a finite resource and that its price tends to increase exponentially, as its reserves decrease[18]. Since Dr. Diesel’s untimely death in 1913, his engine has been modified to run on the polluting petroleum fuel that we now know as “diesel.” Nevertheless, his ideas on agriculture and his invention provide the foundation for a society fuelled with clean, renewable, locally grown fuel. In the 1930s and 1940s vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. Today throughout the world countries are returning to using this form of fuel due to its renewable source and reduction in pollution[17,19].

The naturally occurring oils and fats are triglycerides or triacylglycerols. Oils and fats are primarily water-insoluble, hydrophobic substances in the plant and animal kingdom[17]. The plant or vegetable oils usually contain free fatty acids, phospholipids, sterols, water, odourants and other impurities. They occupy a prominent position in the development of alternative fuels for diesel engine but there are many problems associated with using it directly in diesel engine. These include: coking and trumpet formation on the injectors to such an extent that fuel atomization does not occur properly or is even prevented, decrease in power output and thermal efficiency of the engine, carbon deposits, oil ring sticking, thickening or gelling of the lubricating oil as a result of contamination by vegetable oils, and lubricating problems. Other disadvantages to the use of vegetable oils and animal fats are the high viscosity and lower volatilities that cause the formation of deposits in engines due to incomplete combustion and incorrect vaporization characteristics[17,19,20]. These problems are associated with large triglyceride molecule and its higher molecular mass. To overcome these problems, the oil requires chemical modification and the most commonly used method is transesterification with methanol or ethanol as the physical characteristics of fatty acid methyl or ethyl esters (biodiesel) are very close to those of diesel fuel, and the process is relatively simple. Catalysts for transesterification can be acid, base, enzyme, and heterogeneous catalysts[21,22]. The process of producing biodiesel from vegetable oil or animal fat is shown in the following general equation (**Scheme 1**).



Scheme 1: General equation for transesterification of a triglyceride.

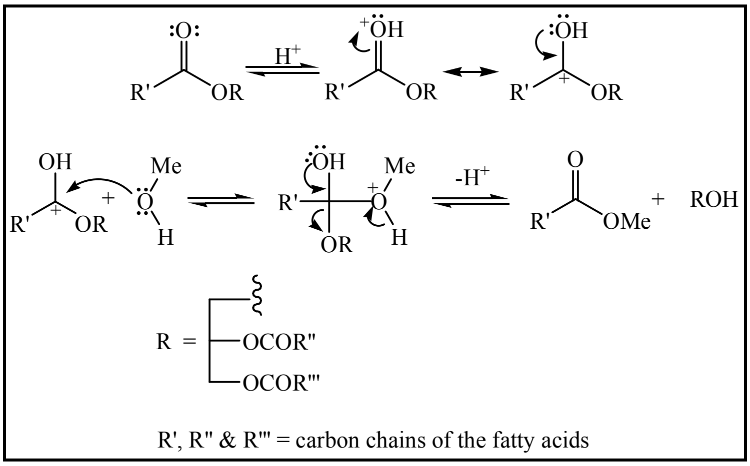
Generally, alcohols used in the transesterification are methanol, ethanol, propanol, butanol and amyl alcohol. The selection of an alcohol is based on several factors including cost and performance considerations. Methanol and ethanol are utilized most frequently, especially methanol because of its low cost and its physical and chemical advantages[5]. This transesterification process has been widely used to reduce the high viscosity of triglycerides which enhances the physical properties of renewable fuels to improve engine performance[17,19,20].

Transesterification undergoes reaction with alcohol in presence a catalyst which may be acid, base, enzyme, and heterogeneous catalysts[12,21,22]. Transesterification is a reversible reaction and proceeds essentially by mixing the reactants. The stoichiometric reaction requires 1 mol of a triglyceride and 3 mol of the alcohol. Transesterification consists of a number of consecutive and reversible reactions. The first step is the conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides, and then monoglycerides to glycerol, yielding one methyl ester molecule per mole of glyceride at each step (**Scheme 2**).

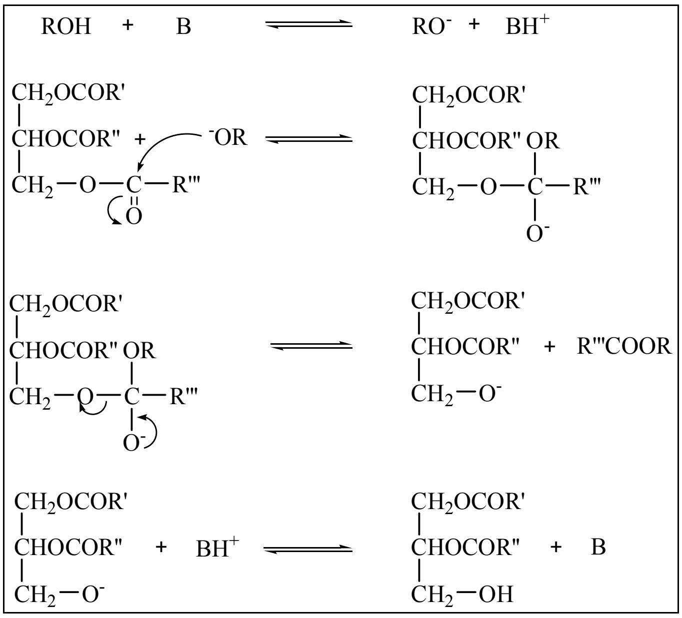
Triglyceride	+	ROH	$\rightleftharpoons$	Diglyceride	+	R'COOR
Diglyceride	+	ROH	$\rightleftharpoons$	Monoglyceride	+	R''COOR
Monoglyceride	+	ROH	$\rightleftharpoons$	Glycerol	+	R'''COOR

Scheme 2: The transesterification reactions of vegetable oil with alcohol to esters and glycerol.

The mechanism of the acid and base-catalyzed transesterification of vegetable oils for a triglyceride is shown in **Scheme 3 & 4** respectively[19,20,22]. However, diglycerides and monoglycerides are also converted by the same mechanism to a mixture of alkyl esters and glycerol.



Scheme 3: Mechanism of acid-catalyzed transesterification of a triglyceride (vegetable oil) with methanol. Transformation of the three ester functionalities may proceed simultaneously or one after another.



Scheme 4: Mechanism of base-catalyzed transesterification of vegetable oil (triglyceride).

For biodiesel production, an alkali-catalysis process has been established that gives high conversion levels of oils to methyl esters[17,19,20]. Biodiesel can also be produced using lipases (both extra cellular and intracellular) as catalyst. But the cost of lipase production is the main hurdle to commercialization of the lipase-catalyzed process. Several attempts have been made to develop cost-effective systems. In terms of production cost, there are also two aspects, the transesterification process itself and the recovery of byproduct *i.e.* glycerol. A continuous transesterification process is one choice to lower the production cost. The foundations of this process are a shorter reaction time and greater production capacity. The recovery of high quality glycerol is another way to lower production cost. Land may be a cost increasing factor for biodiesel production, because of more and more land required to live the growing population. To overcome the land problem, the high yielding biodiesel plants (non-edible producing plants) should be grown in marginal and waste land areas[23]. Biodiesel is a technologically feasible alternative to fossil diesel, but nowadays biodiesel costs 1.5–3 times more than fossil diesel. There are two factors that affect the cost of biodiesel, the costs of raw material (fats and oils) and the cost of processing. The cost of raw materials accounts for 60–75% of the total cost of biodiesel fuel. As far as actual fuel costs are concerned, the cost of biodiesel currently is comparable to that of gasoline. Biodiesel will be a reasonably available engine fuel in the near future. The advantage of biodiesel in this aspect is that it is a derivative of natural products. As demand rises, the production of the required agricultural products can be increased to compensate[24].

Biodiesel feedstock

For biodiesel production, the feedstock is chosen according to quality, availability in each region or country, physico-chemical properties and its production cost. Composition of the oil is also one of the important criteria to determine the suitability of oil as a raw material for biodiesel production. Any fatty acid source may be used for biodiesel production and the common fatty acids found in vegetable oils or animal fats[4] are shown in **Table 1**. Recently, vegetable oils have been attracting more attention worldwide because of their environmental benefits and the fact that they are made from renewable resources and moreover, they are potentially inexhaustible source of energy with energy content close to that of diesel fuel. A variety of biolipids *viz.* virgin vegetable oil feedstock, waste vegetable oil, animal fats and non-edible plant oils can be used to produce biodiesel. Presently, different countries are using different oils as raw materials for biodiesel production owing to its availability and in general the most abundant vegetable oil in a particular region is the most common feedstock. Thus, soybean oil is commonly used in United States, and rapeseed and sunflower oils are used in many European countries for biodiesel production. Similarly, palm oil in Southeast Asia (mainly Malaysia and Indonesia) and coconut oil in the Philippines are the largest source of vegetable oils[4,25-27]. In India and Southeast Asia, *Jatropha curcas*, Karanja (*Pongamia pinnata*) and Mahua is used as a significant fuel source[24]. Every country has specific variety of feedstocks for their biodiesel production. Some countries and their feedstocks used for biodiesel production[28,29] are presented in the **Table 2.** Presently, throughout the world, the researchers have been investigating for finding out the cheaper and economically viable feedstocks for the production of biodiesel. The feedstocks used for commercial production as well as for R & D are presented in **Table 3**. The potential of all these species can be exploited depending on their techno-economic viability for production of biofuels. The potential yields of oils of selected non-edible feedstocks[30] are shown in **Table 4**.

Table 1. Common fatty acids found in vegetable oils and animal fats[4].

Fatty acids	**Number of carbons and double bonds**
Lauric (dodecanoic) acid	C12:0
Myristic (tetradecanoic) acid	C14:0
Palmitic (hexadecanoic) acid	C16:0
Palmitoleic (*cis*-9-hexadecenoic) acid	C16:1
Stearic (octadecanoic) acid	C18:0
Oleic (*cis*-9-octadecenoic) acid	C18:1
Linoleic (9,12-octadecadienoic) acid	C18:2
Linolenic (9,12,15-octadecatrienoic) acid	C18:3
Arachidic (eicosanoic) acid	C20:0
Gondoic (*cis*-11-eicosenoic) acid	C20:1
Gadoleic (*cis*-9-eicosenoic) acid	C20:1
Arachidonic (5,8,11,14-eicosatetraenoic) acid	C20:4
Behenic (docosanoic) acid	C22:0
Eurcic (*cis*-13-docosenoic) acid	C22:1
Lignoceric (tetracosanoic) acid	C24:0
Nervonic (*cis*-15-tetracosenoic) acid	C24:1
Cerotic acid (hexacosanoic) acid	C26:0

Table 2. The Countries and their Feedstocks used for biodiesel production around the World[28,29].

Country	Raw Material or Feedstock
Mexico	Animal fat, Waste oil
Canada	Canola oil, Animal fat
USA	Soybean oil, Waste oil
Brazil	Soybean oil, Palm oil, Caster oil, Cotton oil
Spain	Sunflower oil
France	Rapeseed oil, Sunflower oil
UK	Rapeseed oil, Waste oil
Sweden	Rapeseed oil
Finland	Rapeseed oil, Animal fat
Germany	Rapeseed oil
Italy	Rapeseed oil
India	Jatropha oil, Karanja oil, Mahua oil
China	Jatropha oil, Waste oil
Thailand	Palm oil, Jatropha oil, Coconut oil
Malaysia	Palm oil
Indonesia	Palm oil, Jatropha oil
Russia	Rapeseed oil, Soybean oil, Sunflower oil
Japan	Waste oil
Korea	Waste oil
Philippine	Coconut oil, Jatropha oil
Australia	Waste oil, Animal fat
New Zealand	Waste oil, Animal fat

Table 3. Feedstocks for production of biodiesel.

Non-edible oils		Edible oils	Animal Fats	Other Sources
Yellow oleander[31-33]	Neem (Mellia azadirachta)[47]	Rice bran[60]	Lard[17]	Microalgae[79]
Field pennycress[34]	Moringa oleifera[25]	Rapeseed [62]	Fish oil[77]	Fungi[80]
Jatropha curcas[35,36]	Hemp (Cannabis sativa L.)[49]	Cottonseed[63]	Poultry fat[78]	Algae[80]
Hevea brasiliensis[37]	Simarouba glauca[50]	Soybean[64,65]	Tallow[78]	Yellow Grease[23]
Rocket (Eruca sativa)[38]	Stillingia (Sapium sebiferum[51]	Sunflower[66,67]		Cooking Oil[23]
Terminalia belerica[39]	Guindilla (Guindilia trinervis)[52]	Wheat[68]		
Zanthoxylum bungeanum[40]	Pistacia chinensis[53]	Coconut[69]		
Pongamia glabra[41]	Roselle (Hibiscus sabdariffa)[54]	Canola[70]		
Maclura pomifera[42]	Sapindus mukorossi[55]	Palm[71]		
Camelina sativa[43]	Calophyllum inophyllum L.[56]	Pumpkin[72]		
Elateriospermum tapos[44]	Syagrus coronata[57]	Hazelnut oil[73]		
Schizochytrium limacinum[45]	Pithecellobium monadelphum[8,9]	Coriander[74]		
Orbignya phalerata[46]	Schinziophyton rautanenii[27]	Peanut[75]		
Gmelina arborea[6]	Tobacco seed[58-60]	Corn[76]		
Madhuca Indica[47]	Pongamia pinnata[61]	Oat[68]		
Croton megalocarpus[26]	Silybum marianum[5]	Barley[68]		
Jojoba[48]		Sorghum[68]		

Table 4. Estimated yields of non-edible seed oil plants[30].

Name of plant	Oil seed yield (kg/ha)
Calophyllum inophyllum (Polanga)	4680
Azadirachta indica (Neem)	2670
Jatropha curcas (Physic nut)	1900–2500
Pongamia pinnata/Pongamia glabra	225–2250
Thevetia peruviana (Yellow oleander)	1575
Ricinus communis (Castor)	450
Hevea brasiliensis (Rubber)	40–50
Simarouba glauca (Paradise tree)	900–1200

Table 5. Specification of biodiesel standard[4].

Properties	ASTM D6751	EN 14214
Density (15 ^oC, g/cm^3)	NS	0.86–0.90
Kinematic viscosity (40 ^oC, mm^2/s)	1.9 – 6.0	3.5 – 5.0
Cetane number	47 min	51 min
Flash point (^oC)	130 min	120 min
Sodium (ppm) Potassium (ppm)	Na & K combined 5 (max)	Na & K combined 5 (max)
Acid value (mg of KOH/g)	0.50 max	0.50 max
Iodine value (g I_2 /100 g)	NS	120 (max)
Total sulfur (ppm)	15 max	10 max
NS: not specified. max: maximum. min: minimum.		

Biodiesel is characterized by its density, kinematic viscosity, cetane number, cloud and pour points, distillation range, flash point, ash content, sulfur content, carbon residue, acid value, copper corrosion, and higher heating value. The quality of biodiesel is most important from engine's point of view and various standards have been specified to check the quality[31]. The composition of oil determines the properties of the biodiesel obtained. Since biodiesel is produced from vegetable oils of varying origin and quality, the biodiesel produced must meet the international standards (**Table 5)** before being used as a pure fuel or being blended with conventional diesel fuels[4,7]. The physical characteristics of biodiesel are very close to those of diesel fuels, and therefore biodiesel becomes a strong source to replace the diesel fuels. The conversion of oils or fats into methyl or ethyl esters through the transesterification process reduces the molecular weight to one-third that of the triglyceride and also reduces the viscosity by a factor of about eight and also increases the volatility marginally. The biodiesel esters contain 10–11% oxygen by weight which helps it to burn better than hydrocarbon-based diesel fuels in an engine. The cetane number of biodiesel is around 50 and its higher cetane number improves the ignition quality even when blended in the petroleum diesel. Biodiesel is a clean fuel as it is free from sulphur and aromatics[23]. Biodiesel is receiving worldwide attention because of its renewability, biodegradability, nontoxicity and carbon neutrality[7,15].

Fig. 1. ***Thevetia peruviana*** **(Yellow oleander) plant.**

Fig. 2. Yellow oleander fruits with seeds and kernels.

Thevetia peruviana **(Yellow oleander)**

Thevetia peruviana Schum. known as yellow oleander or milk bush or lucky nut is a small, perennial and evergreen mainly grown as an ornamental plant. It is a dicotyledonous shrub and belongs to the family *Apocynaceae*. It is commonly found in the tropics and sub-tropics regions of the world but it is native to Central and South America[81]. The plant (**Fig. 1**) grows to about 2–6 m in height and the leaves are spirally arranged, linear and about 13–15 cm in length. There are two varieties of the plant, one with yellow flowers known as yellow oleander, and the other with purple flowers known as nerium oleander. Both varieties start flowering after one and a half year and after that it blooms thrice every year[82]. The plant gives fruit throughout the year providing a steady supply of seeds. The fruit, seed and kernel of the plant are shown in **Fig. 2**. The plant, grown as hedges, can produce 400–800 fruits per annum depending on the rainfall pattern and plant age. The flowers are funnel-like with petals that are spirally twisted. The fruits are somewhat globular, with fleshy mesocarp and have a diameter of 4–5 cm. The fruits are usually green in colour and become black on ripening. Each fruit contains a nut which is longitudinally and transversely divided. Mature fruit contains 2–4 seeds in its kernel and the plant bears milky juice in all organs. In Nigeria, *T. peruviana* has been grown for over fifty years as an ornamental plant in homes, schools and churches by missionaries and explorers[81]. *Thevetia peruviana* is still a plant of no economic value, underutilized, and lesser known[31].

T. peruviana plant is particularly known for its ability to produce cardiac glycosides, such as neriifolin and peruvoside, which have a relatively high therapeutic index compared to that of digoxin. The plant has been regarded as a potential source of biologically active compounds *viz*. insecticides, rodenticides, fungicides and bactericides[83]. The seed of the plant contains toxic compounds which are mostly cardiac glycosides and their free aglycones such as thevetin, theveridoside, theveside, cerberin, peruvoside, perusitin and digitoxigenin[84]. Ingestion of *T. peruviana* seed by either man or animal has been reported to result in severe cardiac toxicity which produced marked poisoning symptoms that culminated in death[84]. Other clinical features are severe diarrhoea, abdominal pain, dilated pupils and occasionally convulsions[84]. All parts of plants contain toxic glycosides, the major one reported in seed being thevetin, a bitter principle with a powerful cardiac action. The toxicity of the glycoside is reflected in the accidental poisonings that occur among children that feed on the seed of the plants. Some adults have reportedly died after consuming oleander leaves in herbal teas. It was reported that the kernel of about ten fruits may be fatal to an adult while kernel of one fruit may be fatal to children. Generally, small children and livestock are at higher risk of *T. peruviana* poisoning[81]. Thevetin is pharmacologically the most active constituent, especially on heart. Thevetoxin closely resembles thevetin in pharmacological action but is less toxic. The seeds contain glycosides of neriifolin, acetyl neriifolin and thevetin. Seed oil distillates of *Thevetia peruviana* have been found to contain anti-bacterial activity. The leaves of *Thevetia peruviana* are used to toothache due to caries. It is used in anti-rheumatic, decongestant, febrifuge and used for purge[85].

T. peruviana seed contains 60–65% of oil and the cake contains 30–37% protein[32,81,84]. Despite the fact that there is high level of oil and protein in the seed, it remains non–edible because of the presence of cardiac glycoside (toxins)[81]. The seed has nutritional value and can thus be used as an alternative protein source in animal feed formulation. It would reduce competition between man and livestock for the conventional sources of proteins if it is processed healthy. The oil could also be useful in the production of oleochemicals such as liquid soap, shampoos, alkyd resin and biodiesel[81]. Thus, African countries are encouraged to invest in the cultivation of this potentially rich plant in order to reduce over-dependence on the currently limited sources of protein and oil. The plant can be cultivated in wastelands. It requires minimum water when it is in growing stage. In a hectare, 3000 saplings can be planted and out of which 52.5 tons of seeds (3500 kg of kernel) can be collected. Hence, about 1750 liters of oil can be obtained from a hectare of wasteland[82]. Hated by herbivorous animals, the plant can be grown on roadsides and road-dividers in expressways for beautification, environmental protection and at the same time for the production of biodiesel. Due to high oil and protein contents, and its availability, the plant has a potential for various uses and it may be used for biodiesel production.

Biodiesel is mixture of methyl esters of long-chain fatty acids derived from vegetable oils or animal fats. Oils or fats from different sources have different fatty acid compositions. The fatty acids vary in their carbon chain length and in the number of unsaturated bonds they contain. Vegetable oils and animal fats are triglyceride molecules in which three fatty acid groups are esters attached to one glycerol molecule. Fats and oils are primarily water-insoluble hydrophobic substances in the plant and animal kingdoms that are made up of 1 mol of glycerol and three moles of fatty acids and are commonly referred to as triglycerides[24]. The fatty acid compositions of oils or fats have a major role in biodiesel production processes as well as in quality of biodiesel. The fatty acids present in *T. peruviana* seed oil are myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, arachidic acid and arachidonic acid[32,81]. The fatty acid profiles and physicochemical properties of *T. peruviana* seed oils which are reported in various scientific literatures are presented in **Table 6 & 7** respectively.

Biodiesel fuel properties and engine performance are linked to the fatty acid profiles of raw oils or fats. It is reported that increasing unsaturation level in oil and decreasing chain length leads to decreased viscosity, melting point, cetane number and calorific value of biodiesel[39]. The fuel properties of *T. peruviana* biodiesels reported in various literatures and their comparison with biodiesels obtained from different oil sources are summarized in **Table 8**. It is seen from the **Tables 5 & 8** that most of the fuel properties of biodiesels prepared from *Thevetia peruviana* seed oils meet the properties prescribed in the biodiesel standards ASTM D6751 and EN 14214. Hence, this seed oil sample may be considered as prospective feedstock for biodiesel industries.

Table 6. Fatty acid profiles of *T. peruviana* seed oil.

Fatty acid composition	% composition					
	Deka *et al.*[32]	Oluwaniyi *et al.*[86]	Oseni *et al.*[87]	Three geographical locations in Nigeria (Usman *et al.*[81])		
				North	North central	South
Myristic acid [C14:0]	--	--	--	0.25	0.31	0.41
Palmitic acid [C16:0]	23.28	17.1	17.02	20.17	18.12	20.21
Palmitoleic acid [C16:1]	--	--	0.29	0.26	0.23	0.26
Stearic acid [C18:0]	10.71	11.8	6.24	7.69	6.37	6.39
Oleic acid [C18:1]	43.72	64.3	41.90	46.09	39.91	42.21
Linoleic acid [C18:2]	19.85	6.3	11.89	15.89	12.46	10.83
Linolenic acid [C18:3]	--	--	1.15	0.41	0.74	0.47
Arachidic acid [C20:0]	02.41	--	1.82	--	--	--
Arachidonic acid [C20:4]	--	0.4	--	--	--	--

Table 7. Physicochemical properties of *Thevetia peruviana* seed oil (TPSO).

Properties	TPSO (Deka *et al.*[32])	TPSO (Yarkasuwa *et al.*[33])	TPSO (Adebowale *et al.*[31])	TPSO (Oseni *et al.*[87])	TPSO (Duraisamy *et al.*[88])	TPSO (Ogunneye *et al.*[89])	TPSO (Usman *et al.*[81])
Density (15 °C, g/cm^3)	0.899 (34 °C)	0.921 (30 °C)	--	0.905	0.92	0.843	0.929
Acid value (mg KOH/g)	0.568	4.7	--	--	--	1.33	--
Free fatty acid (mg KOH/g)	0.284	2.4	3.4	1.96	--	0.665	0.62
Iodine value (g I_2 /100 g)	71.2	12.6	84.50	--	--	27.4	79.4
Saponification value (mg KOH/g)	--	412.3	--	--	--	128.5	124.3
Kinematic viscosity (40 °C, mm^2/s)	--	47	--	40.42	48	--	--
Cetane number	--	--	--	--	42	--	--
Pour point (°C)	--	--	--	2	-7	--	--
Flash point (°C)	--	--	--	190	128	108	--
Cloud point (°C)	--	--	--	14	-4	--	--
Refractive index	1.4635	--	--	--	--	1.448	1.461
Oil content (wt.%)	63	67	62	--	--	--	63.3
Moisture content (wt.%)	--	2.2	--	0.09	--	--	--

Table 8. Fuel properties of *T. peruviana* biodiesels (TPB) reported in various literatures and their comparison with biodiesels obtained from different oil sources.

Properties	TPB (Deka *et al.*[32])	TPB (Yarkasuwa *et al.*[33])	TPB (Adebowale *et al.*[31])	TPB (Betiku *et al.*[90])	TPB (Dhoot *et al.*[91])	TPB (Balusamy *et al.*[82])	Nerium oleander (Bora[92])	*T. belerica*[39]	*S. mukorossi*[93]	P. *glabra*[41]	*M. ferrea*[39]	Jatropha[94-96]
Density (15 °C, g/cm^3)	0.875	0.866	0.87	0.887	0.86 (25 °C)	0.839	0.86	0.882	0.876	0.903	0.898	0.88
Kinematic viscosity (40 °C, mm^2/s)	4.33	5.10	4.50	6	5.17	4.2	4.2	5.17	4.63	6.130	6.2	4.4
Cetane number	61.5	--	54.2	123.25	--	47	50	53	56	55	54	57.1
Cetane index	62.9	58.97	--	--	--		--	--	--	--	--	--
Pour point (°C)	+3	-2	--	+1	0	-8	-10	3	- 4	3	3	2
Flash point (°C)	+75	175	125	196	151	110	110	90	140	95	112	163
Cloud point (°C)	+12	3	--	+8	12	-6	-4	6	-1	--	--	4
IBP/FBP (°C)	250/360	--	--	--	--	--	--	130/347	193/383	219/430	210/375	--
Lubricity (60 °C, µm)	263	--	--	--	--	--	--	--	--	--	--	--
Carbon residue (mass%)	0.06	--	--	--	--	--	--	0.0085	0.12	0.781	0.25	--
Acid value (mg of KOH/g)	0.057	--	0.20	0.46	0.3	--	--	0.23	0.14	0.00	0.01	0.40
Iodine value (g I_2 /100 g)	69.9	17.39	84.20	90.23	--	--	--	--	--	--	--	--
Total sulfur (ppm)	--	--	--	--	--	--	--	96	102	50	70	--
Calorific value (kJ/g)	42.279	--	--	--	--	40.46	--	39.22	40.02	43.422	42.23	39.23

Biodiesels from *Thevetia peruviana* seed oils and their fuel properties

Deka *et al.*[32] produced biodiesel from yellow oleander (*Thevetia peruviana*) seed oil and investigated as a highly promising feedstock for biodiesel industries as fuel properties conform to standards set for ASTM D6751 and EN 14214 and in certain aspects better. It is reported that the biodiesel is free from sulfur and has exhibited a higher cetane number of 61.5 that far exceeds the minimum limits of 47 and 51 prescribed in ASTM D6751 and EN 14214 respectively, which is a good indication of fuel's ignition and combustion quality. The kinematic viscosity of the biodiesel at 40 °C was 4.33 mm^2/s that is within the range specified by ASTM D6751 and EN 14214. The density of YOME (Yellow Oleander Oil Methyl Esters) at 15 °C was found to be 0.875 g/cm^3 which is well within the range specified by EN 14214. It is prescribed in ASTM D6751 and EN 14214 that the maximum limit of acid value for biodiesel should not exceed 0.50 mg of KOH/g. The acid value of YOME was found to be 0.057 mg of KOH/g. Iodine value of YOME (69.9 g I_2 /100 g) is also far below the maximum limit of 120 prescribed in EN 14214. It was reported that no sodium was detected in the biodiesel and potassium was present only up to 2.0 ppm. The biodiesel standards ASTM D6751 and EN 14214 contain no specification regarding the heat of combustion. The European standard EN 14213 for use of biodiesel as heating oil prescribes a minimum heat of combustion of 35.0 kJ/g. Deka *et al.*[32] reported that the gross and net calorific values of the biodiesel produced from yellow oleander seed oil are found to be 44.986 kJ/g and 42.279 kJ/g, respectively indicating good fuel properties. The lubricity and ramsbottom carbon residue of the biodiesel is 263 µm and 0.06 mass% respectively. The IBP/FBP of YOME is 250/360 °C and total recovery was 98.5% at 360 °C. The cloud point and cold filter plugging point of YOME are found to be +12 °C and +6 °C, respectively which are not specified in biodiesel fuel standards such as ASTM D6751 and EN 14214. The reported pour point and flash point values of YOME are +3 °C and +75 °C respectively.

Adebowale *et al.*[31] produced methyl esters (biodiesel) from the oil of *Thevetia peruviana* using a two-step reaction system and studied its fuel properties. It was reported that fuel properties of the methyl esters of *Thevetia peruviana* is comparable to European recommendation (EN 14214). The ester content was found to be 98%, while the triglyceride, diglyceride, and monoglyceride content of the biodiesel were 0.10%, 0.20%, and 0.30%, respectively. The iodine value of a vegetable oil or animal fat is almost identical to that of the corresponding methyl esters**.** The biodiesel produced revealed an iodine value of 84 g iodine/100 g which is well below the maximum limit specified in the European recommendation (EN 14214). The free glycerol content was 0.02% while the phosphorus content was less than 1 ppm. It was reported that the biodiesel produced had a density of 0.87 g/cm^3 and a cetane number of 54. The oxidative stability of biodiesel was 30 h and the flash point was found to be 125 °C. The copper strip corrosion test of the biodiesel from *Thevetia peruviana* was found to be in agreement with the European recommendation (EN 14214).

Yarkasuwa *et al.*[33] produced biodiesel (Fatty Acid Methyl Esters, FAME and Fatty Acid Ethyl Esters, FAEE) from yellow oleander (*Thevetia peruviana*) oil and studied fuel properties and its biodegradability. It is reported that there is a drastic reduction in viscosity (at 40 °C) from the seed oil (47 mm^2/s) to the FAEE (5.21 mm^2/s) and FAME (5.10 mm^2/s) of *Thevetia peruviana*. The cetane index reported is 47.19 for ethyl ester (FAEE) and 58.97 for methyl ester (FAME) which falls within the range stipulated for biodiesel by American standard (min 47). Other fuel quality parameters reported are the flash point of 198 °C (FAEE) and 175 °C (FAME), pour point of 4 °C (FAEE) and -2 °C (FAME) and a cloud point of 6 °C (FAEE) and 3 °C (FAME). The biodiesel was tested for biodegradability using *E. coli* and found that the biodiesel from the seeds of yellow oleander is environmentally friendly. The biodegradability values of 81.3% and 86.2% were obtained for FAEE and FAME respectively after a period of 28 days.

Betiku *et al.*[90] produced biodiesel from yellow oleander oil and tested for its fuel properties. Most of the properties compared well with ASTM D6751 and EN 14214 biodiesel specifications. The biodiesel produced is safe to handle as the flash point obtained for the biodiesel is 196 °C which crosses the minimum value of 93 specified in ASTM D6751. It is reported that the kinematic viscosity of the biodiesel meets the specification by ASTM D6751 but is slightly higher than that of EN 14214. Also, the acid value of 0.46 mg KOH g^{-1} oil of the biodiesel is within the limit specified in the standards.

Sahoo *et al.*[97] investigated the feasibility of biodiesel production from *Thevetia peruviana* seed oil and studied its utilization in Compression Ignition engine. In their study, they reported that *Thevetia peruviana* seed oil could be adopted as a potential feed stock for biodiesel production due to its high oil content (62.14%) in seed kernel, low FFA (1.35 mg KOH/g), low viscosity (11.3 cSt) and density (0.91 g/cm^3) in seed oil. Various physico-chemical properties like acid value, saponifation value, unsaponifiable matter, iodine value of *Thevetia peruviana* oil were also determined and showed promising results. The properties of biodiesel from *Thevetia peruviana* were found to be comparable to conventional diesel fuel and comply with the standard for biodiesel

(IS: 15607 and ASTM 6751). The viscosity of biodiesel was found to be 3.67 cSt which is lower than that of diesel. They also studied the fuel performance and emission characteristics of the fuel and the biodiesel fuel was found to be an engine and environment friendly fuel.

Kannan *et al.*[98] prepared biodiesel from *Thevetia peruviana* oil and it was found that the properties of biodiesel were comparable with diesel. The performances of blended diethyl ether (DEE) with biodiesel in the ratios of 5%, 10%, 15% and 20% were investigated. It was reported that most of the blends exhibited higher brake thermal efficiencies (BTE) than pure biodiesel and among the blends, the highest BTE is 29.9% for 20% DEE blend. It was also reported that DEE blend beyond 20% creates vapour locking problems in the fuel line leading to fluctuations in the speed and power of the engine. A reduction of 15% of NO_x emission was reported for 20% DEE blends at full load which was the highest reduction among the blends while compared with biodiesel. In their study, it was found that the addition of DEE with biodiesel reduced the smoke opacity for most of the blends than biodiesel. A reduction of 14.63% in smoke opacity was observed for 20% DEE blend at full load than for biodiesel which was the highest, while 15% blend showed a reduction in smoke opacity of 9.75%. The ignition delay period of 20% DEE blend at full load was found to be 12.7 degree while for biodiesel it was 13.1 degree. The shortened ignition delay period reduces the maximum pressure and temperature for the DEE blends when compared with diesel and biodiesel. It was reported that 20% DEE blend has the maximum pressure of 47.24 bar. Addition of DEE with biodiesel decreased the viscosity and thereby increased the atomization of air fuel mixture. In this study, it has been found that 20% DEE blend with *Thevetia peruviana* biodiesel results in better performance and lesser emissions.

Kannan *et al.*[99] emulsified *Thevetia peruviana* biodiesel with water in the ratios of 5, 10, 15, and 20% for investigation of the engine performance and emission characteristics. In this study, it was reported that 15% emulsified biodiesel showed 6.87% increase in BTE compared to biodiesel and a reduction of 41% in NO_x emissions was found for 20% emulsified biodiesel and 38% reduction for 15% emulsified biodiesel at full load. 3.05% HC reduction was observed for 20% emulsified biodiesel than in biodiesel whereas 1.94% reduction was observed for 15% emulsified biodiesel at full load. 20% emulsified biodiesel showed 9.63% reduction in smoke opacity and 7.22% reduction for 15% emulsified biodiesel. From the study, it was also reported that 20% and 15% water emulsified biodiesels showed higher peak pressure and heat release rates than the other combinations.

Duraisamy *et al.*[88] transesterified *Thevetia peruviana* seed oil with methanol to biodiesel using sodium hydroxide as catalyst and investigated the effect of compression ratio on performance and emission characteristics of 20% biodiesel blended with 80% diesel (B20) for use as fuel in a diesel engine. In this study, various performance and emission parameters like brake thermal efficiency, specific fuel consumption, the exhaust gas temperatures CO, CO_2, HC, NO_x and smoke intensity were measured and analyzed. It was reported that performance of the engine increases appreciably with less brake specific fuel consumption by increasing the compression ratio for biodiesel blend. Also, it was observed that increase in compression ratio significantly reduces the CO, HC, NO_x and smoke emissions but there is a slight increase in CO_2. It was found that an engine fueled with 20% biodiesel blended with 80% pure diesel reveals a significant improvement in performance and reduction in emissions.

Dhoot *et al.*[91] produced biodiesel from *Thevetia peruviana* seed oil by transesterification with methanol using NaOH as catalyst. The properties such as the kinematic viscosity at 40 ºC, density at 25 ºC, flash point, pour point, cloud point, acid value, total ester content, and copper stripe corrosion were investigated and reported. The fuel properties of the biodiesel produced are found to be comparable to those of ASTM and EN biodiesel standards. Thus, *Thevetia peruviana* seed oil can be a potential alternative to produce biodiesel which could be used in the existing engines as a blend with diesel.

Biodegradability of biodiesel

Biodiesel is an alternative and renewable fuel for diesel engines. It is made from biological resources and hence, it is renewable, biodegradable, non-toxic and environment-friendly fuel[5-11]. Also it is free from sulphur and aromatic compounds. Biodegradable fuels have an expanding range of potential applications and the solution for the waste problems of fuels is its more biodegradability. There is growing interest in degradable diesel fuels that degrade more rapidly than conventional disposable fuels. Biodiesel is a non-toxic fuel and degrades about four times faster than petrodiesel and moreover, its oxygen content improves the biodegradation process leading to a decreased level of quick biodegradation[24,100]. Biodiesel metabolizes more easily than diesel because the former is a natural product consisting of fatty acids that are hydrocarbon chains with two oxygen atoms attached at one end and it is being recognized and attacked immediately by enzymes such as acetyl-CoA dehydrogenase[33]. It is reported that biodiesel is highly biodegradable in freshwater as well as soil environments[24]. The biodegradability studies of several biodiesels show that all biodiesel fuels are readily biodegradable in the aquatic environment. It is reported that 90–98% of biodiesel is mineralized in 21–28 days under aerobic as well as anaerobic conditions[24,101,102]. Pasqualino *et al.*[101] reported that after 28 days, more than 98% degradation of pure biodiesel is observed in comparison to 50% and 56% by diesel fuel and gasoline respectively. Heavy fuel oil in 28 day laboratory studies showed a low biodegradation of 11% due to its higher proportion of high molecular-weight aromatics[103,104]. Vegetables oils and biodiesels rapidly degrade and reach to a biodegradation rate of 76-90%[24,105]. Zhang *et al*. reported that vegetable oils degrade slightly less than their modified methyl ester[102]. Yarkasuwa *et al.*[33] studied the biodegradability of *Thevetia peruviana* biodiesels *viz.* FAEE (fatty acid ethyl esters) and FAME (fatty acid methyl esters). It was found that the biodiesels are environmentally friendly, such that after spillage, the FAEE and FAME takes about 28 days to degrade 81.3 and 86.2% respectively. It is not like petrodiesel which takes longer time to degrade to a maximum of 26.82%[33].

Environmental concern

In view of environmental considerations, biodiesel is considered to be a carbon neutral fuel because all the carbon dioxide released into the atmosphere during its consumption as a fuel is being recycled and reused for the growth of vegetable oil crops which is used as feedstock for biodiesel production[106,107]. Biodiesel is the mixture of methyl esters of long chain fatty acids with 2–3 double bonds and hence, it has a higher cetane number than diesel fuel[107]. Biodiesel is free from sulphur and aromatics compounds. It contains 10–11% oxygen by weight. Biodiesel combustion emits lesser pollutants in the environment compared to diesel. It reduces the emission of carbon monoxide (CO), SO_2, hydrocarbon (HC) and particulate in the exhaust gas compared to diesel fuel[107,108]. All emissions associated with 100% pure biodiesel (B100) are lower than conventional diesel except for NO_x. It is reported in most of the literatures that NO_x emissions increase when biodiesel is used as fuel and this increase is mainly due to higher oxygen content for biodiesel. Moreover, the cetane number and different injection characteristics also have an impact on NO_x emissions for biodiesel[109].

Biofuel-driven agricultural expansions, besides contributing to green house gas emissions, can also lead to land-use conflicts among different stakeholders. Koh[110] recently studied the potential habitat and biodiversity losses that may result from an increase in global biodiesel production capacity to meet future biodiesel demands *i.e.* 277 million tonnes per annum by 2050. Demand for biofuels and the resulting impact on food prices may indirectly affect forests and biodiversity by undermining new incentive-driven systems for environmental conservation[30,110]. With the increasing human population worldwide, effective land utilization has now become an important issue particularly in developed countries[111]. Forest reserve is required to ensure efficient utilization and sustainability for proper allocation of land for specific uses such as for agricultural, commercial and domestic. For using non-edible oils as feedstock for biodiesel production, biodiesel yielding (non-edible) plants can be grown in wasteland and infertile land which otherwise would not have much use. This would not only allow wasteland utilization but at the same time would also be used to produce oil crops for biodiesel production without the need to compete with food crops for the limited arable land[111].

Conclusion

Biodiesel, mixture of methyl esters of long chain fatty acids, is an alternative and renewable fuel for diesel engines. It has been chosen as one of the interesting alternative fuels and has been receiving a lot of attention throughout the world as it is renewable, biodegradable, non-toxic and environment-friendly fuel. The cost of biodiesel is the major challenge and obstacle for commercialization and this is due to the high cost of vegetable oils as raw materials in production of biodiesel. Currently, more attention has been devoted to the application of low cost non-conventional and non-edible feedstocks from the wild plants to produce biodiesel. Plants bearing non-edible seeds have the potentials of reclaiming wasteland and do not compete with food crops and utilization of these non-conventional and non-edible feedstocks can be sustainable for biodiesel production. Yellow oleander (*Thevetia peruviana*) seed oil is a promising non-edible biodiesel feedstock that will not compete with food crops. It has several advantages as a renewable biodiesel feedstock because the seed is rich in oil content having 60–65% oil. The plant can be cultivated in wastelands or marginal lands and it requires minimum water as well as minimum care when it is in growing stage. Hated by herbivorous animals, the plant can also be grown on roadsides and road-dividers in expressways for beautification, environmental protection and at the same time for the production of biodiesel. The plant starts flowering after one and a half year and gives fruits throughout the year providing a steady supply of seeds. *T. peruviana* seed oil can be converted into biodiesel. The fuel properties of the biodiesel prepared from *T. peruviana* seed oil are comparable to those of diesel fuels and meet the properties prescribed in the biodiesel standards ASTM D6751 and EN 14214. The biodiesel is biodegradable and has exhibited a higher cetane number of 61.5 which is a good indication of fuel's ignition and combustion quality. An engine fueled with 20% *T. peruviana* biodiesel blended with 80% pure diesel reveals a significant improvement in performance and reduction in emissions. Hence, *T. peruviana* seed oil is a prospective feedstock for biodiesel production.

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