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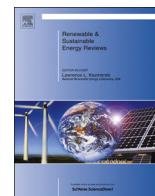
Biodiesel Production and Renewable Energy, View project

An expatiate review of neem, jatropha, rubber and karanja as multipurpose non-edible biodiesel resources and comparison of their fuel, engine and emission properties

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ABSTRACT

The demand for petroleum has risen rapidly due to increasing industrialization and modernization of the world. The limited reserve of the fossil fuels is also dwindling alongside escalation in the prices. The threats from these and food insecurity are, however, drawing the attention of researchers for alternative fuel which can be produced from renewable feedstocks. Biodiesel as the most promising alternate is currently produced from conventionally grown edible plant oils such as rapeseed, soybean, sunflower and palm. The use of the edible oils is worsening the current competition of oil for food and for fuel. Focus on the use of non-edible resources is presently directed to jatropha, mahua, pongamia, calophyllum tobacco, cotton oil, etc. Discrepancies between the expectation and realities regarding these non-edible oils are necessitating efforts for diversification of the feedstocks to resources that could guarantee energy production without affecting food security. Neem, karanja, rubber and jatropha are evergreen multipurpose non-edible plants that are widely available and can be grown in diverse socio-economic and environmental conditions. These plants are described as golden trees that have multiple uses such as for fuels, medicines, dyes, ornamentals, feeds, soil enrichment, afforestation, etc. This study was therefore undertaken to explore the multipurpose of these four non-edible tree plants. Among the highlights of this expatiate review include oil as feedstock for biodiesel, the need for non-edible feedstocks, neem, karanja, rubber, jatropha and their value chains, methods of modifying oil to biodiesel, factors affecting biodiesel production, application of the selected non-edible seed biodiesels to engines for performance and emission characteristics and the outlook.

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1. Introduction

The greater part of the world's energy is currently obtained from fossil resources such as petroleum, coal and natural gas.

These resources are currently facing dramatic dwindling making energy and fuels insecure. In the face of these, there are growing demands for energy and its security, escalation in prices of the limited fossil fuels, increased in openness to renewable energy

resources and a push for expansion in world trade markets new oil producing crops. The increases in instabilities in the centres of petroleum production resulting in fluctuations in crude oil prices also destabilize national, continental and global economies. Couple with these are concerns over global warming resulting from the rate and devastating effects of climate change which consequently affect food security and threatens man's existence. A combination of these and many other factors are the driving forces for alternative and sustainable fuel to augment energy and yet maintain food security [1,2].

Biodiesel, the promising alternative fuel to fossil fuel, is produced from renewable biological resources such as vegetable oils and animal fats. Biodiesel production is modern and techno-logical for researchers [3,4]. It is non-toxic, biodegradable, envir-onmental friendly, has high flash point and can be blended with diesel since the characteristics are similar [5–8] (Table 1).

The oil (feedstock) for biodiesel usually contains free fatty acids, phospholipids, sterols, water, odorants and other impurities. Current studies on biodiesel production are focused on edible oils such as palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil, etc. [9,10]. The edible oil resources represent more than 95% of biodiesel produced in the world due to their availability. However, the edible oil resources are faced with much criticism from the context of food security. Large scale plantation of edible crops for biodiesel for example has led to many countries to demolish their forests which resulted in serious ecological imbalance. The use of edible oils for biodiesel are also associated with disadvantages such as inferior storage, oxidative instability, lower heating value, higher NO_x emissions and high cost of feedstocks [11]. Studies indicate that the costs of feedstocks from edible sources contribute about 60–75% of total cost of biodiesel production [12,13] (Fig. 1). In order to mitigate these, Tan et al. [14] indicated that, the honour lies on using non-edible feedstock. The use of non-edible oils will help solve the food versus fuel concerns, make use of unproductive lands and degraded forests, can be cultivated on fallow lands, irrigation canals, boundaries of roads and fields' not suitable for

crop production [12]. Biodiesel development from non-edible oils could also become major poverty alleviation for the rural poor, help upgrade the rural non-farm sector and ensure sustainable energy production.

Among the non-edible feedstocks, karanja, polanga, mahua, rubber seed, cotton seed, jojoba, tobacco, linseed, jatropha, etc. have so far been studied for biodiesel [15–19]. The commercializa-tion of most of the non-edible feedstocks has, however, presented many challenges including, wide variations in the seed yields and oil contents under different soil and agro-climatic conditions especially, the annual feedstocks as cotton, linseed with conse-quent risks in cultivating them. This expatiate review therefore focuses on neem, karanja, rubber and jatropha as multipurpose non-edible tree plants for biodiesel production towards feedstock diversification for sustainable energy. Among the highlights of the study include, oil as feedstock for biodiesel, the need for non-edible plant oils, neem, karanja, rubber and jatropha and their value chains, methods of modifying oil to biodiesel, factors affect-ing biodiesel production, engine performance and emission char-acteristics of neem, karanja, rubber and jatropha and the outlook. As non-edible tree plants, they can be grown once in a lifetime with continuous harvest (seeds), will not compete with food crops for food, other benefits such as wood, medicines, dyes,
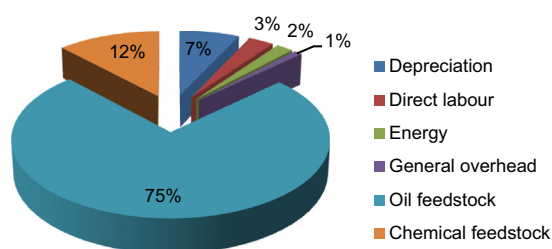
Fig. 1. General cost breakdown of biodiesel production [12,13]. The figure indicates the cost breakdown for biodiesel production. It indicates that the greatest cost in producing biodiesel is the feedstock (75%).

Table 1
ASTM and EN Standards for biodiesel and diesel [5–8,15].

Fuel property	Biodiesel		Diesel
	ASTM D6751	EN 14214	ASTM D975
Composition	HCa (C10-C21)	HCa (C10-C21)	FAMEb (C12–C22)
Cetane number	≥ 47	≥ 51	40–55
Kinematic viscosity (mm^2/s; 40 °C)	1.9–6.0	3.5–5.0	1.9–4.1
Oxidative stability 110 °C (h)	≥ 3	≥ 6	
Cloud point (°C)	–	–	− 15 to 5
Pour point (°C)	–	–	− 35 to − 15
Cold filter plugging point (°C)	–	–	–
Flash point (°C)	≥ 93	≥ 120	60–80
Sulphur content (%, w/w)	≤ 0.05	–	0.05
Ash content (%, w/w)	≤ 0.02	≤ 0.02	–
Acid value (KOH mg/g)	≤ 0.5	≤ 0.5	–
Water content (mg/kg)	–	≤ 500	0.05 (vol%)
Density (20 °C)	–	860–900	–
Free glycerol (%, w/w)	–	≤ 0.020	–
Total glycerol (%, w/w)	–	≤ 0.25	–
Iodine value g/100	≤ 120	≤ 120	–
Group II metals (Ca+Mg) (ppm)	–	–	–
Group I metals (Na+K) (ppm)	–	–	–
Alcohol content (% w/w)	–	≤ 0.2	–
FAAE content (% w/w)	–	≥ 96.5	–
Triglyceride content (% w/w)	–	≤ 0.2	–
Diglyceride content (% w/w)	–	≤ 0.2	–
Monoglyceride content (% w/w)	–	≤ 0.8	–
Sulfated ash content (% w/w)	≤ 0.020	–	–
Copper strip corrosion (50 °C; 3 h)	≤ No.3a	≤ No.1a	–

ornamentals, feeds, soil enrichment, afforestation can be obtained from them.

1.1. Oil as feedstocks for biodiesel

There are more than 350 oil-bearing plants that could be suitable for biodiesel. Among them, soybean, palm, sunflower, rapeseed and peanut oils are considered more potential alternatives for biodiesel [20,21]. However, attention is gradually being shifted to resources such as mustard, jatropha, cotton seed, mahua, karanja, etc. because of their comparative advantages.

The choice of feedstock for biodiesel is primarily based on the availability and cost. European communities for example are self-dependent in production of edible oil with surplus to export. As a result edible oils such as rapeseed is commonly used in European Nations' biodiesel [22,23]. In America, soybeans are commonly used [24,25]. Similarly, countries with coastal areas such as Malaysia, Indonesia and Thailand have surplus palm [26] and coconut oils [27] which are used for biodiesel. In Brazil, the mostly used oils are soybean, castor and palm kernel [28,29]. In various other regions, resources such as sunflower oil, cotton seed oil, pomace oil, canola oil and peanut oil that are potential feedstocks [30–35]. The use of the edible feedstocks for biodiesel is however, aggravating the competition for oil for food and for fuel [36].

1.2. The need for non-edible feedstocks

Non-edible feedstocks have been found to be promising for biodiesel production because of the tremendous demand for edible oils for food [16,37]. Studies indicate that there are large amounts of non-edible oil plants available [38]. Oil resources like jatropha, castor, karanja, rubber seed and neem are not suitable for human consumption due to the presence of toxic compounds in them. Considering the food security situation couple with the competitive nature of edible oils for food, the use of edible oils for biodiesel production will not be sustainable [39]. Also the consequences of converting edible oils to biodiesel (food shortage and increase in commodity price) will also be felt at the world stage. The non-edible oil plants as the obvious choice to diversify the feedstocks can be grown in large scale on non-cropped marginal and wastelands and it is relatively cheaper

to cultivate the non-edible compared with the edible ones (Table 2) [5,40]. Currently the non-edible oilseed plants grown include jatropha (Jatropha curcas) karanja, (Pongamia pinnata), tobacco (Nicotiana tabacum L.), rice bran, mahua (Madhuca indica), rubber (Hevea brasiliensis), castor, linseed, and microalgae [41–56]. The growing of these plants is associated with various advantages including, low water and fertilizers requirement for their growth, resistance to pests and diseases, wide adaptability to different climatic conditions, high seed and oil yield from them, easy propagation, and unpalatable to ruminants [39]. For diversification and to ensure continuous supply of sustainable feedstock for biodiesel, this study was undertaken to explore the potentials of neem, jatropha, rubber and karanja as multipurpose non-edible tree seed oil biodiesel resources and to compare literature on their fuel, engine and emission properties for sustainable energy production [57].

2. Neem and its value chain

2.1. Neem seeds

Neem plant can produce many hundreds and thousands of flowers. In one flowering season, a matured plant can produce a large number of seeds. Neem seeds can yield 40–60% oil. Considering the conservative level of oil content of 30% per seed, annual neem oil production could be up to 30,000 t. For maximum oil production, the moisture of the seeds is kept at a low amount. To ensure continuous seeds availability, the storage of the seeds is very important since their availability is seasonal [57].

2.2. The neem tree

Neem (Azadiractha indica), native to India, belongs to the mahogany family. It is an evergreen plant with a life span of more than 200 years. It is grown in semi-arid and sub-humid regions [57]. Neem is also grown in tropical and subtropical climates and survives at annual mean temperature of 21–32 °C. The plant does well in areas of annual rainfall below 400 mm. Neem tolerates temperatures as high as 48 °C with extremely dry conditions [58]. The plant cannot, however, survive under freezing conditions particularly, in the early stages of growth. Neem grows on almost all types of soils including clay, saline and alkaline soils with pH of 8.5. It can be grown directly by sowing the seed/s or by transplanting nursery raised seedlings with little care. Neem is not palatable to livestocks and therefore not consumed. The plant is also less affected by diseases and pests [57]. Neem trees start bearing harvestable seeds within 3–5 years. Full production can be achieved in 10 years and can continue up to 150–200 years. Averagely, a mature neem plant can produce 30–50 kg of fruits in a year.

2.3. Multiple uses of neem

Neem is a golden tree that has multiple uses. It is used for agroforestry, pest control, toiletries, cosmetics, pharmaceuticals, plant

Table 2
Relative biodiesel production cost [40].

Biodiesel production	Estimated cost, $ barrels
Palm	305
Wheat	125
Rapeseed	125
Soybean	122
Surgar beet	100
Corn	83
Surgar cane	45
Jatropha	43

Table 3
Comparison of the fatty acid composition of the selected non-edible tree oils [5–8,11,70,83,95].

Feedstock	Fatty acid									Oil content
	Myristic acid $C_{14}H_{28}O_2$	Palmitic acid $C_{16}H_{32}O_2$	Palmitoleic acid $C_{16}H_{30}O_2$	Stearic acid $C_{18}H_{36}O_2$	Oleic acid (C18:1) $C_{18}H_{34}O_2$	Linoleic acid $C_{18}H_{32}O_2$	α-Linolenic acid $C_{18}H_{32}O_2$	Arachidic acid $C_{20}H_{40}O_2$	Behenic acid $C_{22}H_{44}O_2$	(wt%)
Neem	0.2–0.26	14.9	0.1	20.6	43.9	17.9	0.4	1.6	0.3	20–30
Karanja		3.7–7.9	–	2.4–8.9	44.5–71.3	10.8–18.3	–	4.1	5.3	25–50
Rubber	2.2	10.2	–	8.7	24.6	39.6	16.3	–	–	40–60
Jatropha	1.4	15.6	–	9.7	40.8	32.1	–	0.4	–	20–60

Table 4
Comparison of the fuel properties of the selected non-edible tree feedstock's biodiesels [51,71,72,84–86,111].

Feedstock	Viscosity at 40 °C (mm²/s)	Density at 40 °C (kg/m³)	Flash point (°C)	Cetane number	Calorific value (MJ/kg)	Cloud point (°C)	Pour point (°C)
Neem (*Adzadiracta indica*)	20.5–48.5	912–965	34–285	51	33.7–39.5	–	
Jatropha (*Jatropha curcas*)	3.7–5.8	864–880	163–238	46–55	38.5–42	–	5
Rubber Seed oil (*Hevea brasiliensis*)	5.81	860	130	37	36.5	4	−8
Karanja (*Pongamia pinnata*)	4.85	890	180	58	34–38	13–15	−3

and animal nutrition and energy generation. As a result of the valuable uses, neem tree is considered as divine tree in some countries. Virtually, every part of neem tree viz., leaf, flower, fruit, seed, kernel, seed oil, bark, wood, twig, root, etc. is useful [57]. The following are, however, other major detailed multiple uses of neem:

2.3.1. For medicinal

All parts of neem (seeds, leaves, flowers and bark) are used for preparing different types of medicines. These include traditional ayurvedic medicines for the treatment of fever, leprosy, malaria, ophthalmia and tuberculosis. Neem is also known to possess curative and preventive properties against various skin infections and other body infections. Extracts of neem leaves are useful for malaria, diabetes, scrofula, erysipelas, treatment [59].

2.3.2. For reforestation and agro-forestry

Neem tree is a unique tree for agro-forestry and a wind break even as single tree. It is compatible with many crops as its deep rooted system avoids competition for soil moisture and nutrients with agricultural crops [57,59]. Neem plantations in rows of 4–6 m apart allow satisfactory growth and yield of various arable crops. It is used for afforestation in saline soils with replacement techniques and can make the site for moderate pastured [59–61]. As a hardy, multipurpose tree, it is good for reforestation and for rehabilitating degraded, semiarid and arid lands.

Neem tree has successfully been used as shelterbelts in arid and semi-arid regions of Sahel and tropical regions [62]. Since neem has thick wood and belongs to mahogany family, it can be used for firewood, construction, furniture and craft-making.

2.3.3. For improvement of environment

Neem can purify air and the environment of harmful materials. The shade of neem tree does not only provide cool but also prevents the occurrence of many harmful diseases. The temperature during hot summer seasons under neem tree can be as low as 10 °C which can be less than the surrounding temperature. Neem is one of the few shady trees that survives in drought prone regions; hence, a life giving tree for the dry coastal regions [57].

2.3.4. For sustainable development

Neem plays an important role for sustainable development. Some of the importance of neem towards sustainable development includes better pest and nutrient management, human health and environmental conservation. Pesticides from neem can neutralize about 500 pests worldwide. The pesticides are environmental friendly than the synthetic ones. This is because chemical insecticides work on the digestive or nervous system of pests while neem compounds work on the insect's hormonal system and thus restricts the development of resistance in future generations. Neem extracts change the life-processing behaviour of insect and make them unable to feed, breed or undergo metamorphosis. Neem's seed cake after oil extraction is used as an excellent organic fertilizer which is far richer in plant nutrients than manure [61]. Neem cake is rich in nitrogen (2–3%), phosphorous (1.0%) and potash (1.4%). The effect and economics of

using neem cake, with one or more than one fertilizer like urea, superphosphate, etc. have been studied and found that there is a saving of 25–50% urea nitrogen coupled with improved yield [61].

2.4. Neem oil production

Methods of producing neem oil is simple and the machinery involved in the oil production is readily available [63,64]. Various methods such as solvent, enzymatic, etc. are available for extraction oil from neem seeds [65,66]. The overall neem oil production process could be described as Harvest ⇒ Seed Dehulling and Cleaning ⇒ Oil Extraction ⇒ Oil Filtration and Purification ⇒ Oil Refining [67]. Yearly, about 540,000 t of seeds can be obtained from a hectare which can yield about 107,000 t of oils and 425,000 t of cake. The oil, being bitter in taste has a great potential to make biodiesel to supplement other conventional sources. Crude neem oil generally contains high amounts of FFAs [39].

2.5. Composition and properties of neem oil and its biodiesel

Per se, neem oil is generally light to dark brown in color, bitter in taste and has a strong odour. The oil is composed of both saturated and unsaturated fatty acids. The fatty acids of neem oil are very important in determining the oil properties. These compositions can be determined by different methods including wet chemical methods [64,68]. The amount and type of FA present in the oil also determine the various physical and chemical properties of its biodiesel.

The fatty acid profile of neem oil from literature is given in Table 3. The oil consists of triglycerides and large amount of triterpenoids which account for the bitter taste. The oil also contains fatty acids such as myristic, palmitic, stearic, oleic, linoleic, arachidic, behenic, and alpha-linoleic [69,70]. The azadirachtin content of neem oil varies from 300 ppm to over 2000 ppm depending on the quality of the crushed seeds. With the fatty acid profile of the oil of about 30% or more in their seed/kernel, neem oil is one of the most suitable oil for biodiesel [69]. The physical and chemical properties of neem biodiesel as compared to conventional diesel are presented in Table 4 [71]. Comparatively, the fuel properties of neem biodiesel are within the limits and comparable with the conventional diesel in Table 1 [15]. Studies indicate that the properties of neem biodiesel could relatively be better in quality than mineral diesel [39].

3. Karanja and its value chain

3.1. Karanja seeds

Karanja seeds contain about 25–50 wt% of oil. The seeds are normally selected based on their conditions; thus damaged seeds are discarded while seeds in good conditions are used for oil extraction. Karanja has been recognized as an invaluable source of oil. A single tree is said to yield 9–90 kg seeds. The seeds contain about 25–40 wt% of oil [69,72,73]. Karanja seed oil is thick, yellow or reddish-brown. 2 kg of matured pods can yield about 1 kg of husked kernels.

3.2. Karanja tree

Karanja tree (*Pongamia pinnata*) is a wonderful tree almost like neem tree which belongs to Papilionoideae family. It originated from India and has been naturalized at Pakistan, Sri Lanka, Australia, Fiji and Japan. It was later introduced to Egypt and the United States [72,74]. Karanja is grown in humid tropical lowlands around the world. Karanja is a medium-sized evergreen or briefly deciduous tree of 15–25 m high, with either straight or crooked trunk 50–80 cm or more in diameter and broad crown [75]. Naturally, reproduction of karanja is by seed but sometimes can be propagated by suckers. Direct sowing is also common and most successful. Seeds require no pre-treatment and germinate within 7 days to 1 month of sowing. Karanja tree is one of the few nitrogen-fixing trees to produce oily seeds.

3.3. Multiple uses of Karanja

Karanja tree has got much importance with excellent medicinal properties. The following are some multiple uses of the plant:

3.3.1. For fuel wood
Karanja is commonly used as a fuel wood in typical local communities. The wood is susceptible to insect attack, making it unsuitable for quality timber. But can be used in agricultural implements, tools and combs. The oil, which is thick yellow–orange has bitter taste and disagreeable aroma. The oil is also used as lubricant, straight fuel, pesticide and for soap making [75,76].

3.3.2. For medicinal
Karanja oil has medicinal value for treatment of rheumatism and skin diseases. The oiled cake constitutes flavonoids, urano-flavonoids, and furan derivatives which are used for treating skin diseases [76]. The leaves can be used for anthelmintic, digestive, and laxative, for inflammations, piles and wounds. The juice is used for treatment of colds, coughs, diarrhoea, dyspepsia, flatulence, gonorrhoea, and leprosy. The root and bark are used for abdominal enlargement, ascites, biliousness, diseases of the eye, skin, vagina itch, splenomegaly, tumours, ulcers and wounds as cleaning gums, teeth and ulcers [75,77,78].

3.3.3. For sustainable development
Karanja cake can be used as fertilizers, pesticides and for organic farming. The seed shells can be used as combustibles. The fresh leaves are eaten by cattle and goats in arid regions [79]. The fruit hull can be used as green manure. The dried leaves can be used as insect repellent in stored grains. The press cake is valued as a pesticide for soil, particularly against nematodes. In rural areas, dried leaves are stored with grain to repel insects. Pounded and roasted seeds are used as fish poison [76].

3.3.4. For improvement of air and environment
Karanja is often planted in homes to serve as shade or ornamental trees and in avenue planting along roadsides and canals [76]. The plant helps in controlling soil erosion and binding sand dunes due to its dense network of lateral roots [75,80].

3.4. Karanja oil production

Karanja oil can be extracted by different methods including, mechanical expeller, cold percolation method and or by soxhlet extraction with solvents and enzymes [81,82]. The mechanical press extraction method is often used since it is simple for extracting all types of oils. This process requires extra time and recovers oil in fewer amounts as compared to other methods.

Seeds of karanja could yield 35% oil by weight. Only 6% is being utilized out of 200 million ton seeds available per annum worldwide.

3.5. Composition and properties of karanja oil and it biodiesel

The fatty acid composition of karanja oil is indicated in Table 3. The oil contains both saturated and unsaturated fatty acids. The dominant fatty acids of karanja oil include palmitic, stearic, oleic, linoleic, arachidic, behenic, arachidic and behenic [5,11,70,83]. The percentage composition of fatty acid is predominantly oleic acid (51.8%) with linoleic acid (17.7%), palmitic acid (10.2%), stearic acid (7.0%), and linolenic acid (3.6%). The composition of the fatty acid determines the properties of its biodiesel. The properties of karanja biodiesel from other studies as compared to the other non-edible tree plants are indicated in Table 4 [72,84,85]. Comparatively, the biodiesel properties are within the limits and comparable with conventional diesel in Table 1.

4. Rubber tree and its value chain

4.1. Rubber seed oil

Rubber seeds are among seeds with high oil content. A rubber seed can contain 50–60 wt% oil while the kernel can contain 40–110 wt% oil [7,16,85]. The oil has high unsaturated fatty acids with 39.6% linoleic acid, 24.6% oleic acid and 16.3% linolenic acid. Although the content of oil in rubber seeds varies amongst different regions, the average oil yield is reported to be between 40% and 50% of seed weight [51,86,87].

4.2. Rubber tree

Rubber tree (*Hevea brasiliensis*) belongs to Euphorbiaceae family. The tree originates from Brazil. It is a forest based tree which is largely produced in Malaysia, India, Thailand and Indonesia. In the wild, the height can reach as tall as 34 m. The tree requires heavy rainfall and non-frost climate condition for optimum production.

4.3. Multiple uses of rubber

The main product of the rubber tree is the latex which is used as a source for natural rubber. Natural rubber is used to manufacture varieties of products that are used in automotives, mining, agriculture, shipping, chemicals, pharmaceutical, and consumer industries. A secondary product is lumber from the wood. Other rubber products such as inflatable, footwear, sporting goods, toys, bicycles and motorcycles tires, and latex products such as globes, prophylactics, medical tubings, medicines and feeding bottle nipples are obtained from rubber tree [88]. The following are the other multiple uses of rubber:

4.3.1. For industrial purposes
Natural rubber accounts for about 30% of global rubber production. The choice of using natural or synthetic rubber or a combination of the two is determined by economic and technical factors. Currently, about 70% of the total natural rubber consumption is in the manufacturing of tyres, tubes and other items associated with automotive transport. It is estimated that some 50,000 different products are made from natural rubber directly or indirectly. Rubber is also used for footwear, boots, shoes, soles or heals, and cable isolation [88]. Other industrial applications of rubber include fabrics, shock absorbers, washers and gaskets, transmission and conveyor belting, hoses, sports goods, household and hospital supplies, contraceptive appliances and paints. Sponge, mattresses and foamed latex are also products from rubber [89].

4.3.2. For fuel and cosmetics

Rubber seeds contain oily shell and kernel. The oil in the shell, after processing is similar to linseed oil which is used as ingredient in paints, varnishes and soaps. Old rubber trees provide valuable wood sources, which can be used for either domestic or industrial fuel (caloric value 4500–4700 kcal/kg) for production of charcoal, manufacturing of pulp for paper industry, manufacturing furniture and medium-dense fibre board, packing cases and pallets, etc. Umar and Esekhade [90] estimated that, a 30 year old plantation of rubber can produce between 150 and 200 t/ha of green wood. Rubber is also a good source of biodiesel [91,92]. When rubber is used for biodiesel, the market value is fairly high [93]. According to Azocar et al. [94], rubber seeds are among the most eligible sources of oil for the biodiesel production.

4.3.3. For feed

The residual cake from rubber, after oil extraction is high in protein and carbohydrates, and after elimination of its toxic cyanhydric acid content by boiling for 15 min at 350 °C, can be used to feed cattle and poultry [89].

4.4. Rubber seed oil production

Different methods are used to extract oil from the seeds of a rubber plant. Some of these include mechanical press, soxhlet extractor, manually operated cylindrical method, solvent extraction and enzymatic method [81]. Depending on the purpose of the oil, the method could vary. The seeds of rubber could weigh between 2 and 4 g per seed. Currently, the oil from the seeds does not have any major industrial applications. The oil content of the seeds could range from 40 to 50 wt [39].

4.5. Composition and properties of rubber seed oil and its biodiesel

Table 2 indicates the composition of rubber seed oil. The oil contains the following saturated and unsaturated fatty acids: palmitic, stearic, oleic, linoleic, and alpha-linolenic [5,11,70,83,95]. The comparisons of the biodiesel properties of rubber seed oil with that of neem, karanja and jatropha oils are also given in Table 4 [51,86]. The characteristics of the rubber seed biodiesel could be compared to those of neem, karanja and jatropha as well as diesel fuel, as indicated in Table 1. The percentage composition of oil in the seed is high in unsaturated fatty acids primarily, linoleic (39.6 wt%), oleic (24.6 wt%) and linolenic (16.3 wt%) [39].

5. Jatropha and its value chain

5.1. Jatropha seeds

Jatropha tree can bear large amount of seeds in a season. The seeds contain 30–40% oil [67]. To produce oil, the seed moisture needs to be maintained at a relatively low temperature. The storage of the seeds is very important for continuous press operation because the availability of Jatropha seeds is seasonal [67].

5.2. Jatropha tree

Jatropha plant is a deciduous tree of 3–5 m in height. Under favourable conditions, the plant can grow to a height of 8–10 m. The tree has a smooth grey bark when cut. The stems usually exude whitish coloured watery latex but becomes brittle and brown when dried [96]. The leaves are green with pale-green at a length of about 6 cm and width of about 15 cm, 3–7 lobes with a spiral phyllotaxis. Jatropha can easily be propagated by seeds or branch cutting.

5.3. Multiple uses of Jatropha

Jatropha plant is very useful for different purposes in different communities in the world. In Africa and America for example, the plant is used as an ornamental plant in gardens for their ornamental foliage and flowers. The plant is also commonly grown as a live hedge around agricultural fields. It is not browsed by goats or cattle. The plant can be cut or lopped at any desired height and is well adapted for hedges around agricultural fields [97,98]. Reviewing different literature, the economic activities associated with multiple uses of Jatropha can be broadly classified as follows:

5.3.1. For oil and fuel

Studies by Gubitz et al. [97] indicate that jatropha seeds contain a lot of oil. The oil content is 35–40% in the seeds and 50–60% in the kernel. The oil contains about 21% saturated fatty acids and 79% unsaturated fatty acids [97]. There are some chemical elements in the seeds which possess poisonous and purgative properties that render the oil non-edible. Studies have indicated that the oil is a good source for biodiesel [99–101]. The oil can be mixed with groundnut oil for adulteration.

5.3.2. For industrial use

Jatropha oil is being extensively used for making soap in India and other countries. At present, *Jatropha curcas* oil is being imported to meet the demand of cosmetic industry [98,102]. In China, a varnish is prepared by boiling the oil with iron oxide. In some villages the oil is used as an illuminant as it burns bricants and candles. In England, it is used for wool spinning. The protein content of Jatropha oil cake may be used as raw material for plastics and synthetics fibres [97,102].

5.3.3. For medicinal

The latex of *Jatropha curcas* contains an alkaloid known as "Jatrophine" which is believed to be having anti-cancerous properties. Jatropha oil possesses purgative properties. It is used as an external application for skin diseases and rheumatism [97,102,103]. The oil is reported to be abortifacient and also efficacious in dropsy, sciatic and paralysis. The tender twigs of the plant can be used for cleaning teeth. The juice is reported to relieve toothache and strengthen gums. The leaf juice is used as an external application for piles. It is also applied for inflammations of the tongue in babies. The twig sap is considered stypic and used for dressing wounds and ulcers. A decoction of Jatropha leaves and roots is given for diarrhoea. The root bank is used for external application for sores [97].

5.3.4. Potential as raw material for dye

The bark of *Jatropha curcas* yields a dark blue dye which is reported to be used in Philippines for colouring cloth, finishing nets and lines [103]. The dye can also be extracted from the leaves and tender stems and concentrated to yellowish syrup or dried to blackish brown lumpy mass. The dye imparts to cotton, different shades of tan and brown which are fairly fast [97].

5.3.5. Use for soil enrichment

Jatropha oil cake is rich in nitrogen, phosphorous and potassium and can be used as organic manure. The plant is potentially used in initiating the process of maintaining surplus livestock by some rural folks in some parts of India, mainly for the purpose of obtaining cow-dung as manure. Tender branches and leaves of the plant are also used as manure for trees [98]. Jatropha oil cakes can replace synthetic fertilizers by undertaking plantations of *Jatropha curcas* on wastelands. The leaves provide plenty organic matter and increase microbial activity including earthworms which is an indication of ecological improvement of site [97,103].
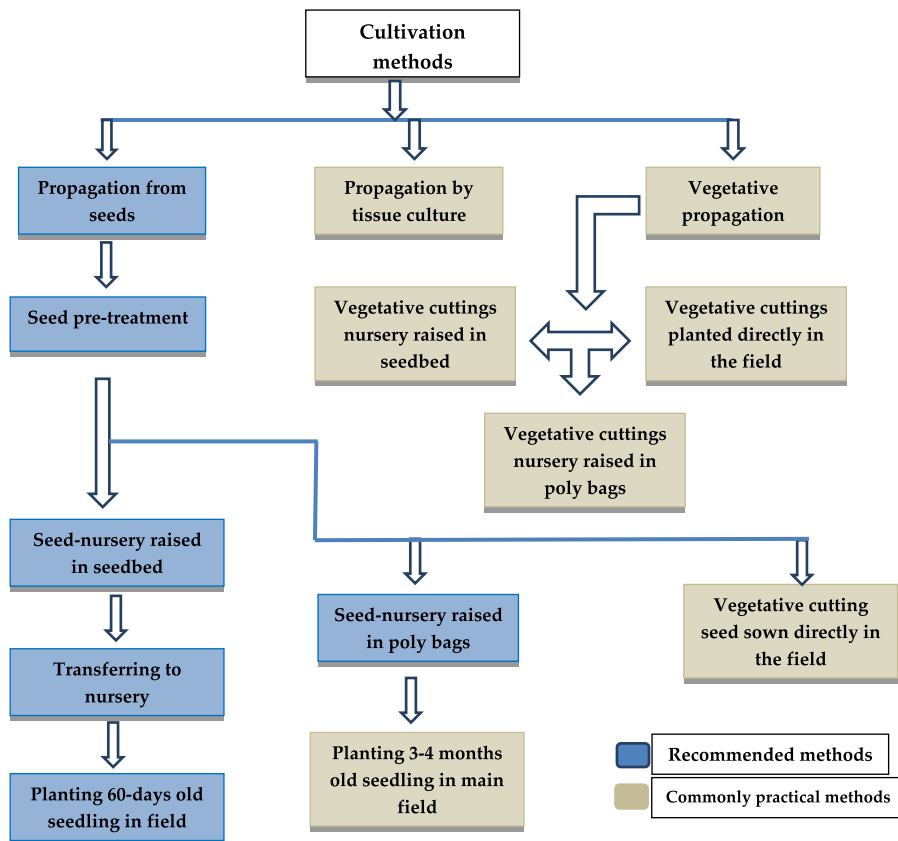
Fig. 2. Flow diagram of neem, karanja rubber and jatropha cultivation and methods [108]. The figure depicts the cultivation methods of non-edible tree plants. The three main methods are propagation from seeds, tissue culture and vegetative propagation. Propagation by seeds goes through seed pre-treatment through to nursery and finally transplanted the 60 days old nursed seedlings to the permanent field. For tissue culture, the plant can be grown directly after the propagation process. For vegetative propagation, the vegetative cuttings can be raised in nursery bed before transplanted to polybags for field planting or the vegetative cuttings can be planted directly on the field.

5.3.6. Use as feeds

Jatropha leaves are used as feed for the some living organisms including tusser silk worm. The leaves are rich in protein but contains some toxic compounds which make them unfit for use as cattle feed. Studies indicate that the poisonous aspect appears to exist in the alcohol soluble fraction of the oil [104]. Studies for the possibility of converting non-edible oil-cake into protein rich cattle and poultry feed on a large scale is being embarked [102–104].

5.3.7. Use as insecticide/pesticide

Jatropha seeds are considered anthelemintic in Brazil. They are ground with palm oil and used as rat poison in Gabon. Aqueous extract of leaves has insecticidal properties [104,105]. In Ghana, the leaves are for fumigating houses against bed bugs. The ether extracts of the leaves show antibiotic activity against *Staphylococcus aureus* and *Escherichia coli*. In Philippines, the juice of the whole plant is used for stupefying fish.

5.3.8. For agro forestry

Simple and cost effective system of growing Jatropha with or without irrigation makes it promising and profitable agro forestry crop both under rainfed and irrigated conditions which ensure its optimal utilization of land, man power, water and financial resources. Jatropha is a plant with low capital investment, short gestation period, long productive period, unlimited employment potential in rural areas, potential for certain productive assets, boosting of village based industries, and above all having a potential for wastelands development [102,106].

5.3.9. Use as non-conventional energy crop

Jatropha oil is an environmentally safe, cost effective and renewable source of non-conventional energy as a promising substitute to diesel, kerosene, LPG, coal, firewood, etc. The fuel properties of jatropha oil closely resemble that of diesel fuel. Studies have shown that the properties of Jatropha biodiesel is suitable for diesel engine [107]. Fig. 2 shows flow diagram of neem, karanja, rubber and jatropha cultivation and methods [108].

5.4. Jatropha oil production

Methods of producing Jatropha oil are simple and the machinery involved in the production is readily available [63,109]. The oil can be produced from decorticates seeds by pressing or solvent extraction which is known in trade as Jatropha. Depending on the purpose of the oil, the extraction method varies [81]. On commercial scale, machineries are involved. The overall Jatropha oil manufacturing process is shown below: Sowing ⇒ Cultivation ⇒ Harvest ⇒ Seed Dehulling and Cleaning ⇒ Oil Extraction ⇒ Oil Filtration and Purification ⇒ Oil Refining [67].

The seeds of *Jatropha curcas* contain viscous oil, which can be used for manufacture of candles and soap, in cosmetics industry, as a diesel/paraffin substitute or extender. This latter use has important implications for meeting the demand for rural energy services and also exploring practical substitutes for fossil fuels to counter greenhouse gas accumulation in the atmosphere.

5.5. Composition and properties of Jatropha oil and its biodiesel

Crude Jatropha oil contains about 14% of FFA, which is far beyond the 1% limit for promoting transesterification reactions
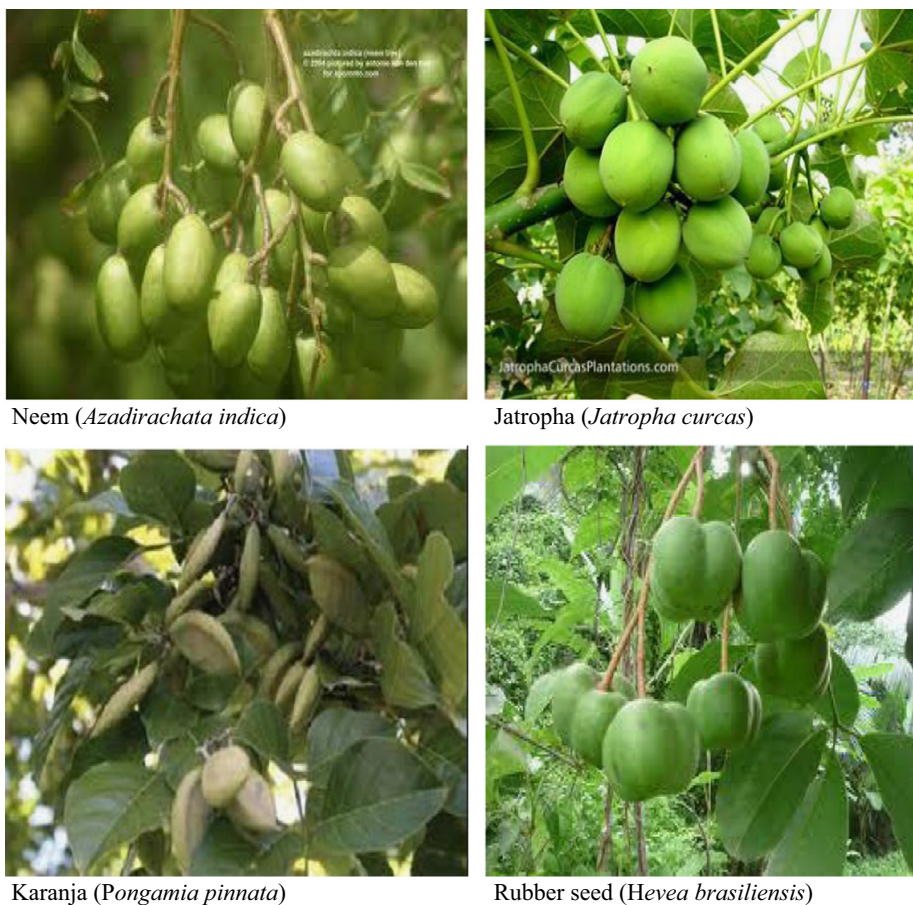
Neem (*Azadirachata indica*)   Jatropha (*Jatropha curcas*)

Karanja (P*ongamia pinnata*)   Rubber seed (H*evea brasiliensis*)

Fig. 3. Neem, karanja, rubber and jatropha feedstock for biodiesel [16,112,113]. The figure indicates the photographs of the seeds of neem, karanja, rubber and jatropha as the non-edible resources for identification purposes.

using alkaline catalysts [42] since an alkaline transesterification requires FFA of less than 1% [110]. Typical fatty acid composition of Jatropha oil as compared to neem, karanja and rubber is shown in Table 3. The oil predominantly contains myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid, and arachidic arachidic acid [5,70,83].

The properties of Jatropha biodiesel from literature as compared to the other non-edible tree plants are indicated in Table 4 [111]. When compared with the international biodiesel standards in Table 1, it can be seen that the biodiesel properties of Jatropha are within the limits and comparable with the conventional diesel in Table 1. Fig. 3 shows pictures of neem, karanja, rubber and jatropha feedstocks [16,112,113]. The oil fraction of *J. curcas* consists of both saturated (14.2% palmitic acid and 7.0% stearic acid) and unsaturated fatty acids (44.7% oleic acid and 32.8% linoleic acid).

6. Methods of modifying oil to biodiesel

A number of methods are available for modification of oil to biodiesel [15,114–116]. Crude oils are modified in order to reduce their viscosities for the obtained product to be suitable for diesel engines. The four primary methods discussed in this study include blending, micro-emulsions, thermal cracking and transesterification [13,117,118].

6.1. Blending of crude oils

Blending is the process of reducing the concentration of a solute in solution, usually by mixing with more solvent. Crude oils can be mixed directly or diluted with diesel fuel in order to improve the viscosity. The resulting solution is well mixed to ensure that all parts of the solution are identical. Vegetable oils are not suitable for direct use in diesel engines. Hence, a blending of 20–40% of it with diesel fuel in diesel engine has yielded good results [70,119]. Studies on blending using various non-edible oils with diesel fuel in diesel engines have been carried out [37,44,120–123]. A blend of 20% vegetable oil and 80% diesel fuel has been successfully reported [5].

6.2. Micro-emulsification

Another approach to modifying vegetable oils is by micro-emulsion. Micro-emulsions are clear, stable isotropic fluids with three components (oil phase, an aqueous phase and a surfactant). The aqueous phase contains salts or other ingredients while the oil phase contains complex mixture of different hydrocarbons and olefins. This ternary phase can improve the spray characteristics by explosive vaporization of the low boiling constituents in the micelles. Micro-emulsions with butanol, hexanol and octanol can meet the maximum viscosity limit for diesel engines [124]. Micro-emulsion can be prepared with or without diesel fuels. The process is considered a dependable approach for viscosity reduction of vegetable oils [124–127].

6.3. Pyrolysis

Pyrolysis as one of the methods for modifying crude oil is the process of converting one substance into another by means of heat or catalyst in the absence of air or oxygen. The pyrolyzed materials

have lower viscosity, pour point, flash point and cetane number greater than conventional diesel and have equivalent calorific value. The pyrolyzed materials have acceptable amount of sulphur, copper corrosion and water content, but unacceptable carbon residue, pour point and ash content [5,7,63,124–126,128]. Sometimes, depending on the operating conditions, the pyrolysis process can be divided into three types thus; conventional pyrolysis, fast pyrolysis, and flash pyrolysis [129,130]. Much studies on the pyrolysis process for biodiesel production from edible and non-edible vegetable oils have been conducted [70,73,119,124,131].

6.4. Transesterification

Transesterification or alcoholysis is the chemical reaction that involves triglyceride and alcohol in the presence of a catalyst to form esters with glycerol as the backbone [132]. Catalyst is usually used to enhance the reaction rate so that the reaction can be completed in a relatively shorter reaction time [133,134]. Several catalysts have been investigated for transesterification. Examples include magnesium, calcium oxides, carbonates of basic and or acidic macro-reticular organic resins, alkane alumina, phase transfer catalysts, sulphuric acids, p-toluene, sulphonic acid and dehydrating agents as a co-catalyst. These catalysts are grouped into alkalis, acids or enzymes [1,110]. Among them, alkali catalysts are usually preferred over acid catalysts because of the higher reactivity and the milder process conditions (lower temperature required) [135]. A successful transesterification reaction produces ester and crude glycerol. Even though esters are the end products of transesterification reactions, glycerine recovery is also important due to the numerous applications in daily products [51].

The two main transesterification processes are acidic and alkaline [42]. Acid catalysts convert the free fatty acid to triglycerides. The by-product of esterification (water) needs to be eliminated since it reduces the effectiveness of the process. The commonest acid used as catalyst is sulphuric acid [136]. However, enzyme catalysts are also gaining prominence in transesterification reactions [13]. Fig. 4 indicates a typical transesterification process [15,112,127,128,137–140].

6.4.1. Alkali catalysed transesterification
Alkali catalyses transesterification is one of the commonest processes. This is because alkali-catalysed transesterification of oils proceeds faster than the other catalysts (acids and enzymes).
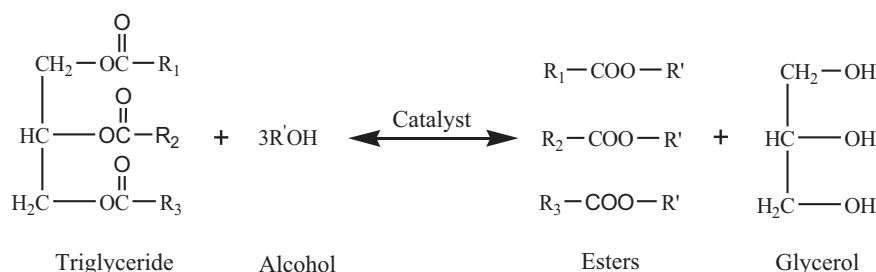
Fig. 4. Typical transesterification process [15,112,127,128,137–140]. The figure indicates typical transesterification which involves triglyceride and alcohol in the presence of a catalyst to form esters with glycerol as the backbone. The process involves three consecutive reversible reactions: conversion of triglyceride to diglyceride, followed by diglyceride to monoglyceride. The triglyceride is then converted into glycerol, giving one ester in each step. Catalyst is usually used to enhance the reaction rate for the reaction to be completed in a relatively shorter reaction time.
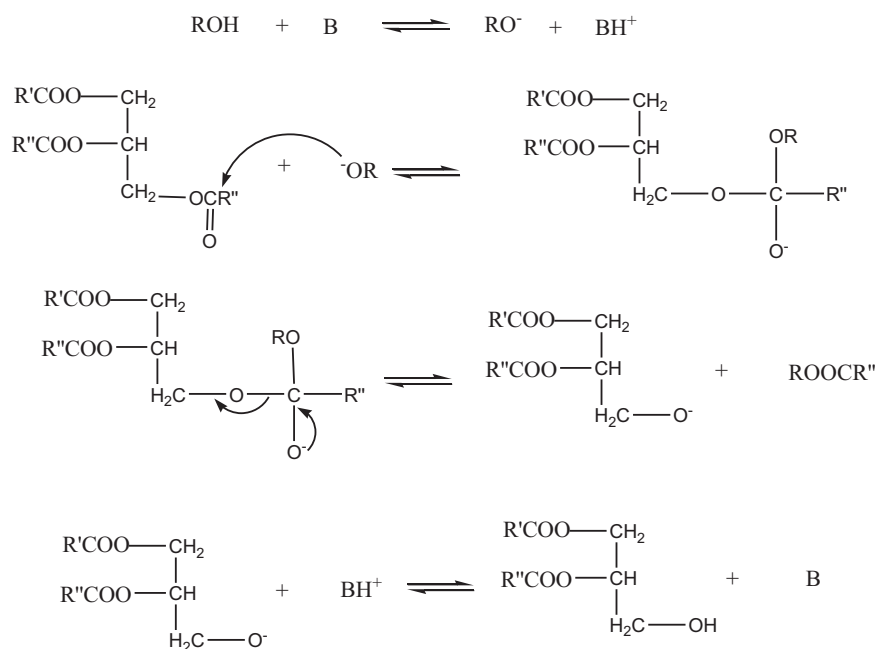
Fig. 5. Mechanism of alkali-catalysed transesterification (B: base) [1]. The reaction mechanism in alkaline transesterification proceeds in three steps: the first step is the reaction of the carbonyl carbon atom with the anion of the alcohol to form a tetrahedral intermediate, from which the alkyl esters and corresponding anions of the diglycerides are formed. A different catalytic cycle is started when the catalyst reacts with a second molecule of alcohol. The diglycerides and monoglycerides at this stage are converted into alkyl esters and glycerol.

The reaction mechanism in alkaline transesterification proceeds in three steps: the first step is the reaction of the carbonyl carbon atom with the anion of the alcohol to form a tetrahedral intermediate, from which the alkyl esters and corresponding anions of the diglycerides are formed. A different catalytic cycle is started when the catalyst reacts with a second molecule of alcohol. At this stage, diglycerides and monoglycerides are converted into alkyl esters and glycerol [1]. Tapanes et al. [141] studied the reaction mechanism of transesterification of *Jatropha curcas* oil as a non-edible and have proven the three step reaction mechanism. According to them, ethyl group can cause the breaking of the ethanol molecule to form an ethoxide anion which becomes more difficult than for the methoxide anion. Usually it is the amount of the FFA that indicates the choice of the catalyst. High FFA content of more than 1%w/w will enhance soap formation and the separation of end products will be difficult, causing a low yield of biodiesel [142]. Fig. 5 indicates the mechanism of alkali-catalysed transesterification [1] (B: base).

6.4.2. Acid catalysed transesterification

Acid-catalysed transesterification process is yet to gain prominence as the base-catalysed. This is due to the slow rate of reaction and the high methanol to oil ratio needed. Acid-catalysts have also got lower activities with the transesterification reaction occurring at higher process temperature than for the base-catalyst [135]. Typically, the use of solid acids as catalysts requires higher temperature and pressure in order to enhance its effectiveness. However, long reaction time makes the process impractical and uneconomical [143]. Acid catalysts can directly produce biodiesel from low-cost lipid feedstock with FFA greater than 6% [144]. Liquid acid catalysts (sulphuric acid) have tolerance and less sensitive to FFA and can simultaneously conduct esterification and transesterification by giving high yields of esters [143]. The mechanism involved in the acid catalyst has to do with the protonation of the carbonyl group of the esters which promotes the formation of carbon cation after a nucleophilic attack of the alcohol produces a tetrahedral intermediate. The intermediate eliminates glycerol to form a new ester and to regenerate the catalyst. Acid-catalysed transesterification can be carried out in the absence of water [1].

Report by Schuchardt et al. [144] using solid super acidic catalysts of sulphated tin and zirconium oxides and tung zirconia for transesterification of soybean oil with methanol at 475–575 K indicated the suitable conditions for acid catalyst. Studies by Shuit et al. [145] on the reactive extraction with an acidic catalyst to produce biodiesel from *J. curcas* L. neem seeds using concentrated sulphuric acid a catalyst gave a yield of 99.8% of Jatropha methyl esters. Fig. 6 shows the mechanism of acid-catalysed transesterification of vegetable oils [140].

R" = [—OH :glyceride
        —OH]

R' = carbon chain of fatty acid

R = alkyl group of the alcohol
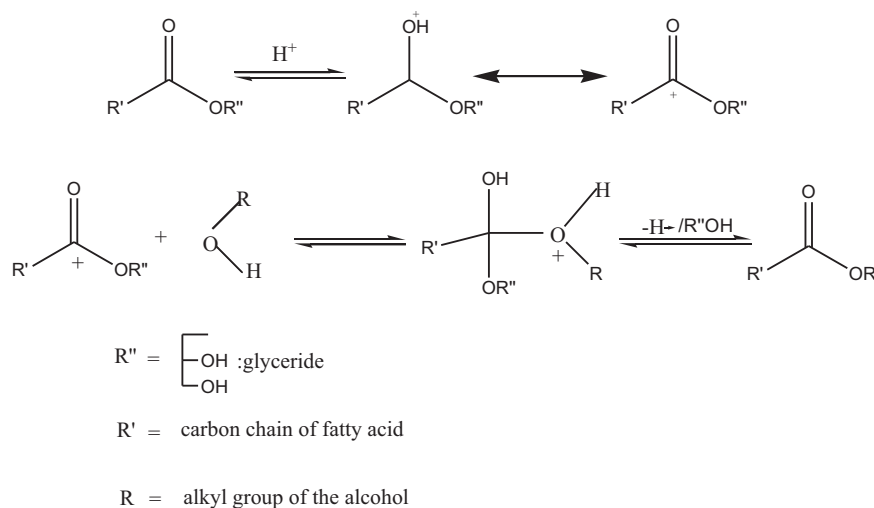
Fig. 6. Mechanism of acid-catalysed transesterification of vegetable oils [140]. The mechanism of acid-catalysed transesterification of vegetable oils involves the protonation of the carbonyl group of the esters which promotes the formation of carbon cation after a nucleophilic attack of the alcohol which produces a tetrahedral intermediate. The intermediate eliminates glycerol to form a new ester and to regenerate the catalyst. Acid-catalysed transesterification can be carried out in the absence of water.

Table 5
Catalysed transesterification of non-edible oils with optimized reaction variables [138,142,145,148,151,162,164–167].

Alcohol type	Molar ratio of alcohol to oil	Catalyst used	Catalyst amount (%)	Optimum reaction condition	Biodiesel yield (%)
Methanol	5.9:1	H_2SO_4	15	60 °C, 24 h	99.8
Methanol	1:1	Rhizopus oryzae	4	30 °C, 60 h	80
Ethanol	4:1	Pseudomonas cepacia	10	50 °C, 8 h	98
Methanol	43:1	–		320 °C, 8.4 MPa, 4 h	100
Dimethyl carbonate	14:1	–		300 °C, 9 MPa, 15 h	97
Methanol	3:1	–		290 °C, 11 MPa, 15 h	99
Methanol	5:1	NaOH	1	60 °C, 90 min	98
Methanol	4.2:1	NaOH	1.4	65 °C, 120 min	90
Methanol	6:1	KOH	1	65 °C, 60 min	99
Methanol	9:1	KOH	2	60 °C, 120 min	95
Methanol	11:1	KOH	1.1	66 °C, 120 min	93
Methanol	12:1	Alumina loaded with potassium nitrate	6	70 °C, 360 min	84

6.4.3. Enzyme-catalysed transesterification

Enzymatic transesterification using lipase catalyst is becoming more attractive due to the easy product separation, less waste-water, easy glycerol recovery and absence of side reactions [146]. Lipases are generally known to act on long chain fatty acids alcohol better than the short chain type. Mild reaction conditions are conducted in the biochemical process. However, biocatalysts are more expensive and their regeneration and reusability are limited with long operation time [143]. The reaction yields of enzyme-catalysed transesterification are unfavourable compared to the base-catalysed reactions and thus render the process and uneconomical [1,143].

Studies on lipase-catalysed process i.e. Novozym (*Candida antarctica* immobilized on acrylic resin) for biodiesel production has indicated effectiveness of lipase catalyst for biodiesel [147]. But the complexity of lipase purification process is restricting its use on larger scale. Tamalampudi et al. [148] have suggested the production of biodiesel using the whole cell of lipase producing *Rhizopus oryzae* (ROL) immobilized onto biomass support particles (BSPs) as the way forward.

6.4.4. Non-catalytic supercritical alcohol transesterification

The essence of non-catalytic supercritical alcohol is to provide a new way of producing biodiesel. Studies indicate that increasing the ratio of reaction temperature to a supercritical temperature can have a favourable influence on ester conversion [1,149,150]. One advantage of this method is that, it makes purification of biodiesel much easier as no catalyst is required during the super-critical transesterification processes which prevent soap formation or saponification reaction. The presence of water which has negative impact using conventional transesterification is also no longer an issue during the formation of methyl esters in this process [1,138]. However, the drawbacks of this process are due to high temperature and pressure that result in high cost of the apparatus. Co-solvents such as CO_2, hexane, propane, calcium oxide and subcritical alcohols are added to the reaction mixture to lower the operating temperature and pressure and the amount of alcohol needed [144].

Hawash et al. [151] have revealed that 100% yield of biodiesel can be obtained in 4 min using supercritical methanol at a temperature of 593 K (320 °C) with a pressure of 8.4 MPa of oil at molar ratio of 43:1 methanol to oil.

7. Factors affecting biodiesel production

7.1. Reaction temperature

The rate of reaction is strongly affected by the reaction temperature. A high reaction temperature can decrease the viscosity of the oil which can lead to an increase in reaction rate. Ideally, the reaction temperature should be less than the boiling point of the alcohol (boiling point of methanol is at 60–70 °C at atmospheric pressure) to ensure that the alcohol will not be evaporated. If the reaction temperature goes beyond its optimum limit, the yield of biodiesel decreases since a higher reaction temperature will accelerate saponification reaction with consequent reduction in yield [2,133]. Depending on the type of oil, the maximum yield is obtained at temperatures between 60 and 80 °C [13,138,152,153].
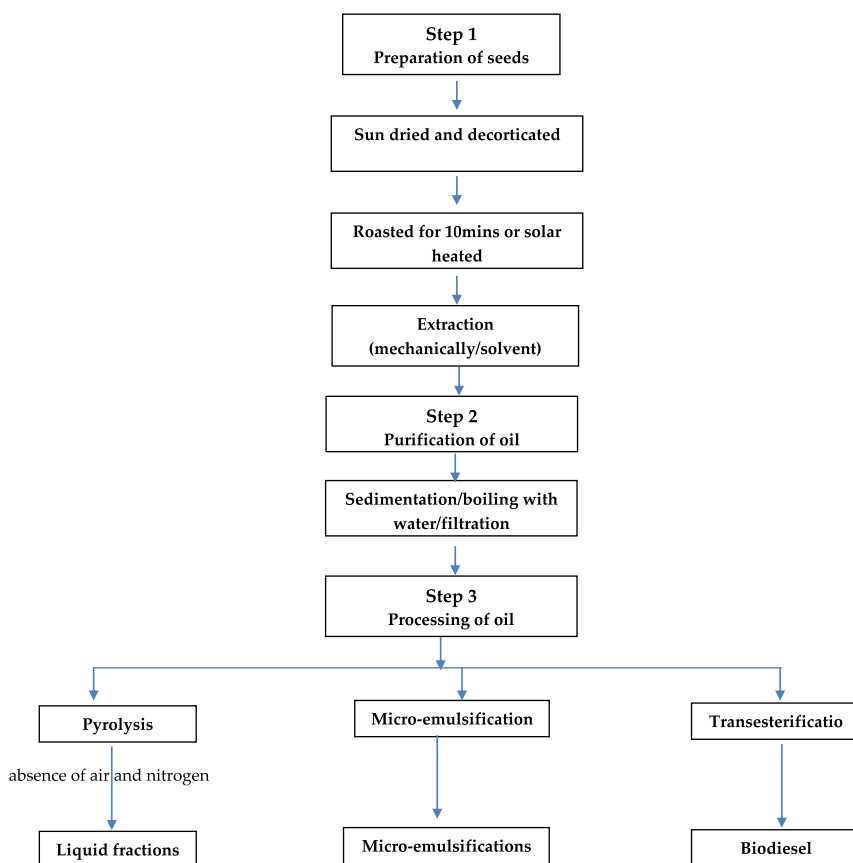
Fig. 7. Process flowchart of neem, karanja, rubber and jatropha seed to biodiesel [168]. The flow chart indicates that the non-edible oil resources' conversion to biodiesel goes through three major steps: Step I starts from seed preparation through drying, solar heating to oil extraction. Step II continuous from oil purification that involves sedimentation, boiling with water and filtration. Step III, the purified oil is then used to transform to biodiesel using any of the discussed transformation methods (pyrolysis, micro-emulsion, transesterification).

Table 6
Engine performance results using neem biodiesel at different test condition [173–179].

Type of engine	Test condition	Result	
		BSFC	BTE
DI, WC, 4S, 1-Cylinder, RP: 5.2 kW, RS: 1500 rpm, CR: 17.5:1.	Constant speed of 1500 rpm, duel fuelling	–	About 5% reduced, compared to diesel
DI, WC, 4S, 1-Cylinder, NA, RP: 9.8 kW, RS: 2000 rpm, CR: 20:1.	Varied blends (B5, B10 and B15), Speed (600–1200 rpm) and varied BMEP	–	Improve with increase in fuel supply till 1000 rpm and decrease when speed is beyond 1000 rpm
DI, D:425 cm^3, 4S,1-Cylinder, RP: 7.5HP, RS:1500, CR: 15.5:1	Varied loads (4, 8, 12, 16 and 20 kg) with constant speed 1500 rpm	Reduce with increase of loads	Improve with increase in engine loads
DI, WC, 4S, 1-Cylinder, RP: 3.7 kW, RS: 1500 rpm, CR:16.5:1	Constant speed and variedloads (1000–4000 W)	Slightly improved at low load when compared with fossil diesel fuel	Slightly reduced at higher loads compared with diesel fossil
DI, WC, 4S, 1-Cylinder, RP: 5.2 kW, RS: 1500 rpm, D: 661 cm^3, CR: 17.5:1	Varied BMEP (100, 200, 300, 400, 500, 600 and 650) and constant speed 1500 rpm	8.25% reduced at part load and 27.25% higher at full load than that of fossil diesel	63.11% higher than that of fossil diesel at part and 11.2% lower at full load
DI, WC, 4S, 1-Cylinder, NA, RP: 5HP, RS: 1500 rpm, CR: 16.5:1	Constant speed and varied BP (0–5 kW)	–	Less than that of fossil diesel fuel at all loads condition
DI, AC, 1-Cylinder, RP:4.4 kW, RS: 1500 rpm, CR: 17.5:1.	Varied blends (B10, B20, B30, B40 and B50), constant speed and different break power	Slightly improved for B20 and all biodiesel were closed to fossil diesel fuel	Reduce with the increased of blend ratio
DI, WC, 4S, 1-Cylinder, RP: 5.2 kW, RS: 1500 rpm	Varied blends (B20, B40, B60, B80 and B100), varied BMEP and constant load	27.75% higher at full load status	Increase (7.01%) at full load condition
DI, NA, 4S, 1-Cylinder, RP: 3.5 kW, RS: 1500 rpm, CR: 16.5:1	Varied blends (B5, B10, B15, B20), different loads and constant speed 1500 rpm	–	Increase with increase of percentage of biodiesel in the fuel at all loads
DI, WC, 4S, 1-Cylinder, RP: 8 HP, RS: 1800 rpm, CR: 16.5:1	Varied loads and constant speed of 1800 rpm and varied blends (B10, B20)	Improved by 23.38% and 12.12% of B10 and B20 compared with fossil diesel	Reduce with all blends when compared with fossil diesel

NB:
Definition for engine parameters: DI=direct injection, WC=water cooled, S=stock, AC=air cooled, IC=intercooled, TC=turbocharger, CI=compression ignition, RP=rated power, D=displacement, RS=rated speed, EGR=exhaust gas recirculation, CR=compression ratio.
Engine performance parameters: BSFC=brake specific fuel consumption, BSEC=brake specific energy consumption, BTE=brake thermal efficiency.Engine emission parameters: NO_x=nitrogen oxide, BSU=Bosch smoke unit, CO=carbon monoxide, HC=hydrocarbon.

Table 7
Engine performance result of karanja biodiesel at different test condition [44,180–183].

Type of engine	Test condition	Result	
		BSFC	BTE
D:3 D:3.44 l, WC, AVL make CI, 3-cylinder, RS:2200 rpm, PS: 44.1 kW, CR:18.1	Full throttle at varied speeds (1200 rpm, 1400 rpm) and varied blends (20%, 50% and 100%)	Increases with increase of blend ratio and decreases with increase engine speed	–
		For part throttle experiment BSFC decrease with more than 20% blend	
DI, WC, 4S, 2-cylinder, RP: 10HP, RP: 7.5 kW, petter Kirloskar CI engine, RS:1500 rpm, CR:16.5:1.	Constant speed (1500 rpm) and varied blends (5%, 10%, 20% and 30%)	Slightly higher (min 0.313 kg/kwh) as compared to fossil diesel	Reduced when compared with fossil diesel
DI,WC, 1-cylinder, AV-1, 4S, CS, CI engine, RP:3.67 kw, D:552.92 cm³, CR:17.5	Varied blends (10%, 20%, 50%,75%) and constant speed (1500 rpm)	Improved when use preheated lower blend up to 50%	Slightly improve (0–25%) compared with diesel fuel as oil use without pre-heating
DI, WC, 4S, 1-cylinder, CI engine, RP:5.9 kW, CR:17.5	Constant speed (1500 rpm), 20% blend and varied load conditions	Lessened with increase in load	BTE was highest at all loads
DI, WC, 4S, 1-Cylinder, CI engine, RP:6 kW	Varied blends (5%, 10%, 15% and 20%) and varied load (0%, 20%, 40%, 60%, 80% and 100%), constant speed (1500 rpm)	Slightly improved as all blends when compared with fossil diesel	Slightly improved at lower loads and reduce at higher loads as compared to neat fossil based diesel fuel
DI, WC, 4S, 1-Cylinder, CI engine, RP:7.5 kW, CR: 16:1	Varied loads (10%, 25%, 50%, 75%, 85% and 100%), varied blends (20%, 40%, 60%, 80%) and constant speed 3000 rpm	0.8–7.4% lower at 20% and 40% blend, and higher with increase of blend ratio	Improve with increases per cent of load
DI, WC, 4S, 1-Cylinder, CI engine, D: 553 cm³, RP: 3.75 kW, CR: 16.5	Varied loads (33.3%, 66.6% and 100%), varied blends (20%, 40%,60% and 80%) and constant speed 1500 rpm	Increase till 40% blend ratio	Slightly reduce with higher blend ratio
DI, WC, 4S, 1-Cylinder, CI engine, D: 553 cm³, RP: 4.476 kW, CR: 16.5:1	Varied blends(10%, 25%, 50% and 100%) and constant speed (1200 rpm)	–	Almost same when compared with fossil diesel
DI, WC, 4-Cylinder, CI engine, D: 3298 cm³, RP: 70 kW, CR: 17.5:1	Constant speed, varied loads and blend (B100, B90M10)	–	Increase of 4.2% at high load condition
DI, WC, 4S, 1-Cylinder, CI engine, RP:3.5, CR:17.5:1,	Constant speed (1500 rpm) and varied loads	Reduce at higher load condition	Improved significantly at higher load condition

7.2. Molar ratio of alcohol to oil

The stoichiometric ratio for transesterification reaction requires 3 mols of alcohol to 1 mol of triglyceride to yield 3 mols of fatty acid esters and 1 mol of glycerol. Excess alcohol is used during transesterification to ensure that the oils will be completely converted to esters when the forward reaction is more favourable. A higher alcohol to triglyceride ratio can result in a greater ester conversion in a shorter period [115,154,155]. The molar ratio is also associated closely with the type of catalyst used. For base-catalysed transesterification, where the free fatty acids are usually less than 1%, molar ratio of methanol to oil of 5:1 or 6:1 is sufficient to convert the oil to biodiesel [42,156]. However, when the percentage of free fatty acids in the oil is high, a molar ratio of 20:1 or more is needed (when using acid-catalysed transesterification) [143,157].

7.3. Catalyst concentration

Catalyst concentration is a very important factor that determines the transesterification yield. Basic catalysts are usually preferred to acid catalysts because of the higher reactivity with low process temperature [135,158–160]. Freedman et al. [161] indicated that sodium methoxide is more effective than sodium hydroxide upon mixing sodium hydroxide with methanol. This results from the reduction in the amount of water. As the catalyst concentration increases, the conversion of triglycerides and the yield of biodiesel also increase till maximum yield is reached. A concentration of NaOH in the range of 1.0–1.4% (w/w) has been found to produce 90–98% conversion neem oil to methyl ester [142,162]. For the concentration of KOH ranging from 0.55% to 2.0% (w/w), 95–99% biodiesel has been obtained [42,110,156,163]. The yields can, however, reduce with addition of the alkali catalysts beyond the optimum [13].

7.4. Reaction time

Conversion rate increases with reaction time. Usually the reaction begins slowly resulting from the mixing and dispersion of alcohol onto the oil difficulty. The reaction, however, proceeds faster with time until maximum yield is reached [115,161]. For base-catalysed transesterification, the yield of biodiesel reaches maximum at a reaction time of 120 min or less [142,163,164]. Acid catalysed transesterification, however, requires an even longer reaction time than the base-catalysed reaction since base catalysts exhibit higher reactivity than acid catalysts [135]. The reaction time needed during the conversion of triglycerides to biodiesel may range from 18 to 24 h [145]. An excess reaction time can lead to a reduction in the product yield due to the backward reaction of transesterification, causing more fatty acids to form soaps [13,152]. Table 5 indicates catalysed transesterification of non-edible oils with optimized reaction variables [138,142,145,148,151,162,164–167] while Fig. 7 shows the process flowchart of neem, karanja, rubber and jatropha plants seeds to biodiesel [168].

8. Engine performance of the selected non-edibles tree oils' biodiesel

8.1. Application of neem biodiesel to diesel engine

There are quite a number of investigations on engine performance and emission characteristics of neem biodiesel in diesel engines. Typical studies conducted on engine performance of neem biodiesel, for example have shown that brake thermal

Table 8
Engine performance result of rubber seed oil biodiesel at different test condition [120,184].

Type of engine	Test condition	Result	
		BSFC	BTE
DI, WC, 4S, 1-Cylinder, CI engine, RP: 5.5 kW, RS: 1500 rpm	Varied loads, varied blends (B20, B40, B60, B80 and B100) and constant speed (1500 rpm)	Improved when compared with fossil diesel	Increase with the increase of blend ratio compared to fossil diesel
DI, WC, 1-Cylinder, 4S, CI engine, RP: 5.5 kW, RS: 1500 rpm	Varied loads, varied blends (B10, B20, B50, B75 and B100) and constant speed (1500 rpm)	Reduce with increase of engine load and used higher percentage of biodiesel	Improved with the increased of amount of biodiesel in the blend
DI, WC, 4S, 1-Cylinder, D: 661.5 cm³, RP: 4.4 kW, RS: 1500 rpm, CR: 17.5:1	Constant speed (1500 rpm) and varied load (25%, 50%, 75%, 100%), Duel fuelling	–	Increased about was 1.33% and 1.14% at full load condition
DI, WC, 4S, 1-Cylinder, DI, 4S, CI engine, RP:5.5 kW, RS: 1500 rpm	Constant speed (1500 rpm) and varied load condition	Greater than that of diesel for duel fuel mode operation	Reduce for incomplete combustion than fossil diesel
DI, WC, 4S, AC, 1-cylinder, AC, CI engine, RP: 4.4 kW, RS: 1500 rpm CR: 17.5:1	Use net RSO and various diethyl ether with RSO (50 g/h, 100 g/h, 150 g/h, 200 g/h and 250 g/h) and full load condition	–	3.4% reduced as compared to diesel fuel using net RSO. But improved with using DEE with RSO
DI, WC, 4S, 1-Cylinder, RP: 5.5 kW, RS: 1500 rpm, CR:16.5:1	Varied loads and constant speed 1500 rpm	34.8% higher than that ofdiesel fuel at 70% load	4.95% lower than that of fossil diesel at full load

Table 9
Engine performance result of jatropha biodiesel at different test conditions [18,111,185–187].

Type of engine	Test condition	Result	
		BSFC	BTE
DI, WC, 4S, 1-Cylinder, D: 1007 cm^3, CR: 18.5:1	Varied blends (B10, B20, B50 and B100) and varied speeds (1000–2400 rpm)	Greater than that of fossil diesel	Reduced when compared with fossil diesel fuel
DI, WC, 4S, 1-Cylinder, 4S, RP: 5HP, RS: 1500 rpm, CR: 16.5:1,	Varied blends (B20, B40, B50, B60, B80 and B100) and varied loads (25%, 50% 75% and 100%)	Reduced when compared with fossil diesel when B20 is used, for other blends it is almost same as diesel	Higher than that of diesel fuel about (20–80%) blends
DI, WC, 4S, 3-Cylinder, D: 3440 cm^3, RS: 2200 rpm, CR:18:1	Varied speeds (1200,1800 and 2200 rpm) and varied blends (B20, B50 and B100)	Improved with increase in percentage of biodiesel in the fuel, but decreased with increased in engine speed	–
DI, WC, 4S, 1-Cylinder, RP: 8 HP,RS: 1500 pm	Varied blends (B25, B50, B75 and B100) and constant speed	Increased with the increased of percentage of biodiesel in the fuel	Was 7% reduced when compared with fossil diesel for B100
DI, TC, 4S, 4-Cylinder, D: 1609 cm^3, RP: 84.5 kW, RS: 3800 rpm CR: 18.5: 1,	Varied speeds and full load condition	Greater than that of fossil diesel	Almost same as compared with fossil diesel
DI, WC, 4S, 1-Cylinder, D: 815 cm^3, RP: 8.82 kW, RS: 2000 rpm CR: 17:1	Varied speeds (1500 and 2000 rpm) and varied load	Average 9.3% and 6.8% increased for 1500 rpm and 2000 rpm	0.2–3.5% and 0.1–6.7% improved at 1500 rpm and 2000 rpm
DI, 4S, AC, 1-Cylinder, D: 947.8 cm^3, RP: 7.4 kW, RS: 1500 rpm, CR: 17.5:1	Varied blends (B5, B10, B20, B30 and B100) and varied loads (20%, 40%, 60%, 80% and 100%)	Higher than that of diesel fuel and increase with the increase of blend ratio	Decreased with the increased of percentage of biodiesel in the fuel compared with diesel
DI, 4S, AC, 1-Cylinder, D: 395 cm^3, RP: 5.59 kW, RS: 3600 rpm, CR: 18:1	Varied speeds (1800, 2500 and 3200 rpm)	Higher than that of diesel fuel	Reduced compared with fossil diesel fuel

Engine emission results of neem biodiesel at different tests conditions [174–177,179,188–190].

Type of engine	Test condition	Emission			
		NO$_x$	HC	CO	Smoke
DI, WC, 4S, 1-Cylinder, RP: 5.2 kW, RS: 1500 rpm, CR: 17.5:1,	Constant speed 1500 rpm, duel fuelling	–	Improved with increase In engine load	Increased at dual mode operation	Slightly, lower when compared with fossil diesel fuel
DI, WC, 4S, 1-Cylinder, NA, RP: 9.8 kW, RS:2000 rpm CR: 20:1,	Varied blends (B5, B10 and B15), varied speed (600–1200 rpm) and varied BMEP	Improved when compared with fossil diesel fuel	–	Reduced compared with diesel fuel	Reduced compared with diesel fuel
DI, WC, 4S, 1-Cylinder, RS: 1500 rpm, RP: 3.7 kW, CR: 16.5:1	Constant speed and varied loads (1000–4000 W) condition	Lower than that of fossil diesel fuel	Slightly reduced compared with diesel	Reduced when compared with fossil diesel	Slightly reduced at all loads
DI, WC, 4S, 1-Cylinder, D: 661 cm^3, RP: 5.2 kW, RS: 1500 rpm, CR: 17.5:1	Varied BMEP (100, 200, 300, 400, 500, and 650) and constant speed 1500 rpm	Decreased about 3.22% at part load and 6.06% at full load condition	Slightly reduced 5.26% at part load and 2.59% at full load status	Improved at increased in BMEP	–
DI, WC, 4S, NA, 1-Cylinder, RP: 5HP, RS: 1500 rpm, CR: 16.5:1	Constant speed and varied BP (0–5 kW)	37% Reduction for pure oil and 19% reduction for methyl ester at full load	Increased 54% and 24% for pure oil and methyl ester at full load	Increased at 40% for pure oil and 20% for methyl ester at full load	Greater than that of diesel fuel
DI, AC, 1-Cylinder, RP: 4.4 kW, RS: 1500 rpm, CR: 17.5:1	Varied blends (B10, B20, B30, B40 and B50), constant speed and varied break power	Improved with the increased in engine load	Lower compared with fossil diesel	Reduced at all load compared with fossil diesel	Increased with the increased of percentage of biodiesel in the fuel and increased engine load
DI, WC, 1-Cylinder, RP: 5.2 kW, RS: 1500 rpm	Varied blends (B20,B40, B60, B80 and B100), varied BMEP and constant speed 1500 rpm	Reduced 6.06% at full load	Reduced 2.59% at full load	–	18.39% reduction at full load condition
DI, 4S, NA, 1-Cylinder, RP: 3.5 kW, RS: 1500 rpm, CR: 16.5:1	Varied blends (B5, B10, B15, and B20), varied loads and constant speed 1500 rpm	Increased slightly at full load condition	Increased with the addition of ethanol in the blends at all loads	Reduced with the percentage of ethanol in the fuel is higher at high loads	Reduced at higher load with the addition of ethanol in the blends

Table 11
Engine emission of karanja oil biodiesel at different tests conditions [18].

Engine type	Test condition	Emission			
		NO_x	HC	CO	Smoke
DI, WC, AVL make CI engine, 3 cylinder, D:3.44 l, RP: 44.1 kW RS:2200 rpm, CR:18.1	Full throttle at varied speeds (1200 rpm, 1400 rpm and 2200 rpm) and varied blends (20%, 50% and 100%)	Slightly increased with increase in blend ratio	Reduce with increase in bland ratio	Slightly increase with increase in blend ratio	Reduction with increase in blend ratio
DI, WC, 4S, CS, 1-cylinder, 4S, CI engine, RP:3.67 kW, D:552.92 cm³, CR:17.5	Varied blends (10%,20%, 50%,75%) and constant speed (1500 rpm)	–	Lower with use of lower blends when compared with fossil diesel	Increase to 10 g/kwh use without pre-heating blend	Smoke density almost same compared with diesel fuel
DI, WC, 4S, 2-cylinder, petter Kirloskar CI engine, RP: 10HP, RP:7.5 kW, RS:1500 rpm, CR:16.5:1	Constant speed (1500 rpm) and varied blends (5%, 10%, 20% and 30%)	Increase 12% compared with fossil diesel	Showed higher HC emission	Increase at increases in blend ratio	–
DI, WC, 4S, 1-Cylinder, CI engine RP:6 kW 4S, 1-cylinder, CI engine, RP:5.9 kW, CR:17.5	Varied blends (5%, 10%, 15% and 20%) and varied load (0%, 20%, 40%, 60%, 80% and 100%) Constant speed (1500 rpm), 20% blend and varied load condition	At 20% blend and 80% load give 4% lower NO_x as compared with fossil diesel. Increases 10–25% compared with fossil diesel	Slightly lower at 10% blend and 70% load Reduce with use of net biodiesel and blend	Closely 4% reduction Reduce with use of netbiodiesel and blend	Blends Reduce with use of net biodiesel and blend
DI, WC, 4S, 1-Cylinder, CI engine RP:7.5 kW, CR: 16:1,	Varied loads (10%, 25%, 50%, 75%, 85% and 100%), varied blends (20%, 40%, 60%, 80%) and constant speed 3000 rpm	Averagely, 26% reduction when compared with fossil diesel	–	Reduce 60% at slightly low load condition	Smoke density min 20% decrease and maximum 80% decrease
DI, WC, 4S, 1-Cylinder, CI engine, D: 553 cm³, RP: 4.476 kW, CR: 16.5:1,	Varied blends(10%, 25%, 50% and 100%) and constant speed (1200 rpm)	Increases 15% NO_x emission	–	Reduced by 50% as compared with fossil diesel	B100 reduced smoke by 43%
DI, WC, 4S, 1-Cylinder, CI engine D: 553 cm³, RP: 3.75 kW, CR: 16.5.	Varied loads (33.3%, 66.6% and 100%), varied blends (20%, 40%, 60% and 80%) and constant speed 1500 rpm	Lowered with increase of blend ratio	Reduce with increase of blend ratio	Slightly higher than baseline fossil diesel	–
DI, WC, 4-Cylinder, CI engine D: 3298 cm³, RP: 70 kW CR: 17.5:1	Constant speed, varied loads and blend (B100, B90M10)	–	Slightly higher at low load condition	Reduced significantly at higher load maximum, 46.5% decrease at full load	Lower at high 80% load

efficiency (BTE) for neem oil methyl esters is nearly close to diesel [169–171].

8.2. Engine performance using neem biodiesel

Rao et al. [172] studied the performance characteristics of neem biodiesel in single cylinder four stroke, DI, water cooled Kirloskar engine with compression ratio of 16.5:1, rated power 3.7 kW at 1500 rpm. Their study indicated a slight drop in the engine efficiency using neem biodiesel when compared with fossil diesel. Other issues of the biodiesel were poor combustion characteristics which were possibly due to the high viscosity of neem biodiesel. Their study also indicated a drop in the thermal efficiency. However, the brake thermal efficiencies of B10, B20 blends were close to fossil diesel. According to Ragit et al. [169], the BTE increase for all the blends but not beyond that of fossil diesel. The highest BTE obtained using neem biodiesel at part load was 16.53%. The BTE, however, decrease with diesel at full load. The BSFC of neem methyl esters was lower at part load and higher at full load when compared with diesel [169].

Neem biodiesel generally gives slightly lower brake thermal efficiency and higher brake specific fuel consumption when compared with diesel [173–176]. But in some instances it gives higher brake thermal efficiency than diesel fuel [177–179]. Table 5 indicates results of different studies on engine performance using neem biodiesel. In most instances, neem biodiesel gives lower brake thermal efficiency with higher fuel consumption which could be due to the lower calorific value of the methyl esters. It can be seen from the engine performance studies (Table 6) that the BTE significantly increased with increase in the neem methyl esters' percentage and the engine load. The BSFC also decreased at a percentage of 8.25% at part load condition at constant speed.

8.3. Engine performance using Karanja biodiesel

Table 6 indicates various studies on engine performance using karanja biodiesel. Karanja methyl esters give higher brake thermal efficiency at higher load and higher brake specific fuel consumption as the blend ratio of biodiesel to diesel increases [44,180,181]. Contrast to these findings, other studies indicate that karanja methyl esters give lower brake thermal efficiency at higher load condition and higher brake specific fuel consumption as the blend ratio of biodiesel to diesel increases [182,183]. Evidently from Table 7, it can be deduced that the increase in engine load leads to the increase in BTE and reduction in the amount of biodiesel in the blend, BSFC reduce at an amount of 0.8% with lower blend ratio and higher engine speed, the power of the engine increases about 6% with decrease in karanja methyl esters' amount in the fuel blend.

8.4. Engine performance using rubber seed biodiesel

Studies on engine performance using rubber seed methyl esters have been reviewed (Table 7). Most of the studies indicate that BSFC increases when using rubber seed methyl esters in a diesel engine. According to Verhey and Mathiyazhagan [120,184] higher brake thermal efficiency and brake power as well as engine load increase with increase in percentage of biodiesel in the blend. Results from Table 8 indicate that 1.1–1.33% increase in performance efficiency was obtained at full load condition. It can also be observed from Table 8 that the increase in percentage of biodiesel in the blend and the engine speed increases with increase in the engine power. But the increase in engine load and biodiesel percentage led to decrease in BSFC. The Diethyl Ether (DEE) injection using rubber seed oil shows higher peak pressure with higher BTE.

Table 12
Engine emission results of rubber seed biodiesel tests at different conditions [120,184,191].

Type of Engine	Test condition	Emission NOx	HC	CO	Smoke
DI, WC, 4S, 1-Cylinder, CI engine RP: 5.5 kW,	Varied loads, varied blends (B10, B20, B50, B75 and B100) and constant speed (1500 rpm)	Slightly increased with the increase in biodiesel blends	–	Reduce with increasing percentage in biodiesel in the fuel and low load	Reduced with higher the concentration of biodiesel blend
DI, WC, 4S, 1-Cylinder, CI engine RP: 5.5 kW	Varied loads, varied blends (B20, B40, B60, B80 and B100) and constant speed (1500 rpm)	–	–	About 0.13–1.13% lower compared to fossil diesel	Increased with increase in engine load
DI, WC, 4S, 1-Cylinder, D: 661.5 cm³ RP: 4.4 kW, CR: 17.5:1	Constant speed of 1500 rpm and varied load (25%, 50%, 75%, and 100%)	Improved with all fuel condition	–	Reduced at all load condition with the induction in hydrogen for all injected fuel	Reduced smoke level 37.09% at full load condition
DI, AC, 4S, 1-cylinder, CI engine, RP: 4.4 kW, RS: 1500 rpm, CR: 17.5:1	Various diethyl ether (DEE) (50 g/h, 100 g/h, 150 g/h, 200 g/h and 250 g/h) and full load	13% Higher compared with diesel fuel	Reduced when using DEE operation when compared with diesel fuel	Reduce with using DEE operation compared with fossil fuel	Large reduction in smoke emission (about 6.1–4 BSU)
DI, WC, 4S, 1-Cylinder, RP: 5.5 kW, RS: 1500 rpm, CR:16.5:1	Varied loads and constant speed 1500 rpm	Higher compared with diesel fuel at all load	Lower when compared with diesel fuel	0.037% lower than compared with fossil fuel	
DI, WC, 4S, 1-Cylinder, CI engine, RP:5.5 kW	Constant speed of 1500 rpm and varied load	–	–	Higher than that of fossil diesel in all operations	Slightly higher than that of fossil diesel with at high load

Table 13
Engine emission results of jatropha biodiesel tests at different conditions [18,186,187,192].

Type of engine	Test condition	Emission			
		NO$_x$	HC	CO	Smoke
DI, WC, 4S, 3-Cylinder, D: 3440 cm^3, RS: 2200 rpm CR: 18:1	Varied speeds (1200,1800 and 2200 rpm) and varied blends (B20, B50 and B100)	Higher than that of fossil diesel	Improved with the increased biodiesel percentage	Reduced with the increased in percentage of biodiesel in the fuel	Reduced with the increased in biodiesel percentage
DI, WC, 4S, 1-Cylinder, D: 1007 cm^3, RS: 2400 rpm, CR: 18.5:1	Varied blends (B10, B20, B50 and B100) and varied speeds (1000–2400 rpm)	About 3.29–10.75% increased compared with diesel fuel	14.91–27.53% reduced with the increased in biodiesel percentage in the fuel	6.51%–12.32% reduced with the increased of blend ratio	Reduced compared with fossil diesel at higher percentage of biodiesel blend
DI, TC, 4S, 4-Cylinder, D: 1609 cm^3, RP: 84.5 kW, RS: 3800 rpm, CR: 18.5: 1	Varied speeds and full load	About 5–10% reduction	Less than that of fossil diesel fuel	About 10–40% reduced compared with fossil diesel fuel	Reduced when compared with fossil diesel
DI, WC, 4S, 1-Cylinder, RP: 5HP, RS: 1500 rpm CR: 16.5:1	Varied blends (B20, B40, B50, B60, B80 and B100) and varied loads (25%, 50%, 75% and 100%)	Lower when compared with fossil diesel	Lower than that of fossil diesel fuel	Lower when compared with diesel fuel	–
DI, WC, 4S, 1-Cylinder, D: 815 cm^3, RP: 8.82 kW, RS: 2000 rpm, CR: 17:1	Varied speeds (1500 and 2000 rpm) and varied load	Lower with the increased in engine speed	Reduce with the increased in engine speed	Lower compared with diesel fuel at pick load	–
DI, WC, 4S, 1-Cylinder, RP: 8 HP, RS: 1500 rpm	Varied blends (B25, B50, B75 and B100) and constant speed	Increased with the increased in biodiesel percentage in fuel and higher than that of diesel fuel	Reduce with the increased in biodiesel percentage	Higher than that of diesel fuel at high load	Slightly lower than that of fossil diesel
DI, AC, 4S, 1-Cylinder, D: 947.8 cm^3, RP: 7.4 kW, RS: 1500 rpm, CR: 17.5:1	Varied blends (B5, B10, B20, B30 and B100) and varied loads (20%, 40%, 60%, 80% and 100%)	Slightly higher than that of fossil diesel	Reduced with the increased in blend ratio	Decreased with the increased percentage of biodiesel in the fuel	Reduced with the increased of blend ratio
DI, AC, 4S, 1-Cylinder, D: 395 cm^3, RP: 5.59 kW, RS: 3600 rpm, CR: 18:1	Varied speeds (1800, 2500 and 3200 rpm)	Slightly higher than that of fossil diesel	Lower than that of fossil diesel	Slightly lower than that of fossil diesel	Lower when compared with fossil diesel

8.5. Engine performance using Jatropha biodiesel

Studies indicate that Jatropha biodiesel gives higher thermal efficiency with higher fuel consumption [111,185,186]. In some instances, the blends of Jatropha biodiesel with diesel give better brake power than diesel fuel [18]. However, some studies have shown that some conditions (such as age of the engine) can lower brake thermal efficiency even if Jatropha biodiesel is blended [111,187]. Studies on engine performance results at different test conditions are indicated in Table 8. From Table 9, it can be seen that an increase in biodiesel percentage in the blend leads to increase in engine power. The percentage of BTE slightly increased at a medium engine speed and 0.1–6.7% at higher speed. The BSFC also increased at 6.8% with increase in percentage of biodiesel in the blend.

9. Engine emission characteristics of the selected non-edible oils biodiesels

9.1. Engine emission characteristics using neem biodiesel

Quite a number of studies have been conducted on the engine emission characteristics of neem oil methyl esters. Sundraapandian and Devaradjane [188] undertook a theoretical and experimental studies to investigate the performance and exhaust characteristics of neem, jatropha and karanja biodiesels. Their study indicated that CO, NO_x, HC and smoke emission could reduced to 18%, 3%, 18% and 12% respectively for neem biodiesel when compared to fossil diesel.

Other studies on neem biodiesel in diesel engine indicates that there are low emissions of CO, HC and NO_x when compared with diesel [174,176,177,179,189]. Different studies, however, indicated higher emission of CO, HC, NO_x and smoke opacity [175,190] of neem biodiesel. Table 9 shows studies on engine emission characteristics of neem biodiesel in diesel engine at different conditions. From Table 10, it can be deduced that, there was reduction in CO as a result of higher amount of ethanol in the fuel blends. However, higher BMEP and engine load gave higher CO emission (about 20–40%). There was also an increase in HC emissions of the engine (about 24–54%) with an increase in engine load. But at some specific conditions, HC emission decreased (between 2.59% and 5.26%). There was also a drop in NO_x emission (of about 3.2–6.06%) under partly loaded and fully loaded conditions.

9.2. Engine emission characteristics using karanja biodiesel

Table 11 shows the engine emission characteristics using karanja biodiesel. Evidently from the various studies presented in Table 11, the operating conditions and the percentages of the biodiesel blends significantly had effects on engine emission characteristics. Even though some of the studies showed higher CO and NO_x emission, others indicated lower CO, HC and smoke emission [18]. The following were found upon critical analyses of the different works: at low load condition, CO emission decreased at an amount of between 4% and 46.5%, lower HC was due to higher load and lower blend ratio (10% biodiesel), with the increase in biodiesel amount in the blend the PM reduce, the amount of NO_x emission was increased by 12% with the increase in biodiesel amount in the fuel but reduced by 4% at 20% biodiesel blend. The smoke level was also reduced (20–43%) at higher load and higher blend ratio.

9.3. Engine emission characteristics using rubber biodiesel

Various studies on the engine emission characteristics of rubber biodiesel is presented in Table 12. The data indicates that rubber seed biodiesel have lower emission than fossil diesel [120,184]. But, at some specific conditions, rubber seed biodiesel had higher engine emissions (CO, HC, NO_x) [191]. The comparison of the engine emissions characteristics in Table 12 indicates that at lower biodiesel blend and higher load condition CO emission reduces (about 0.13–1.13%), CO and HC emissions decreased considerably with diethyl ether (DEE) additive at higher load and lower biodiesel percentage, at higher biodiesel percentage and high load condition NO_x emission increased (about 13%). DEE addition decreased the smoke level greatly.

9.4. Engine emission characteristics using jatropha biodiesel

Collated studies on engine emission characteristics of jatropha biodiesel are presented in Table 13. The results indicate lower emission of CO, HC, NO_x and smoke opacity as compared to diesel [18,186]. In some instances, engine emission went down significantly [18,187,192]. From Table 13, different experimental engine emission results indicate that engine emission of CO, HC, NO_x and smoke opacity reduced. Upon critical evaluation, an increase in CO and HC emissions as a result of higher engine load with EGR gradually reduced which could be due to higher biodiesel amount in the fuel blends, decrease in CO (6.51–12.32%) and HC reduced about 14.91–27.53% NO_x which could be due to higher amount of biodiesel in fuel blends, the NO_x emission decreased with increased EGR. The NO_x emissions increased (about 3.29–10.75%) at some specific conditions. The higher smoke opacity was as a result of the higher engine load. Fig. 8 shows the schematic diagram of engine performance and emission experiment set-up [80,185,193].

10. Outlook for neem, karanja, rubber and jatropha and their biodiesels

It is obvious that using the available edible oil for biodiesel production will worsen the current food versus fuel competition. However, growing neem, karanja, rubber and jatropha as non-edible oil tree plants on waste and abandoned lands means these resources will profitably be used for biomass and energy generation besides other benefits including medical, forestry or agro-forestry, improvement in environment, sustainable agriculture, etc. Farm practices that depend on fertilizers, biocides and pesticides usage sometimes poses threats to the ecology as a result of pollution to the soil fauna and flora. Using the farm lands to grow these multipurpose non-edible trees plants will be the favourable route to promote organic farming. The promotion of these multipurpose non-edible tree plants for biodiesel as another channel of marketing them can help curb the high rate of youth employment through job creation. Their large scale plantation practices will also increase income to the rural populace through job creation which will go a long way to improve the economy. High job creation through integrated farming and biodiesel practice will offer competition for labour with other employment avenues which will have the tendency to increase the income levels of employees since they will be offered more than one opportunity at a time. Promoting these multipurpose non-edible tree plants will ensure regular and available seeds for a longer period of time as they can be harvested for more than 50 years before replacement. Diversifying feedstocks to this multipurpose tree plants will also help countries that have been strategically positioned because of their absolute dependence on fossil fuels to wean themselves off from oil import dependency which could be an economic achievement.
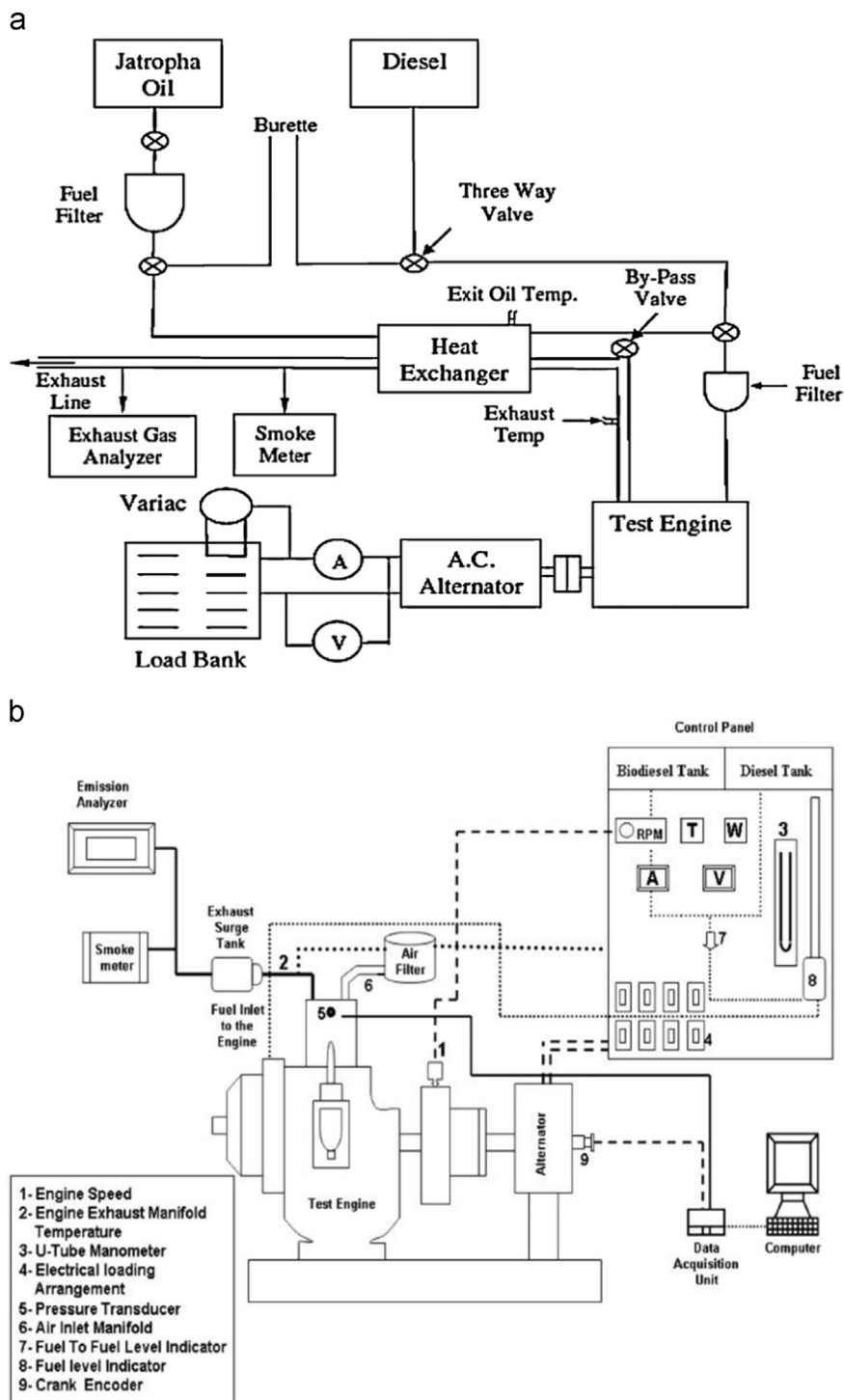
Fig. 8. a. Schematic diagram of engine performance [80,185]. The figure indicates the flow chart for a diesel engine sample for testing performance characteristics of biodiesel samples. b. Schematic diagram of engine emission set-up [193]. Fig. 8b is a representative diagram showing the flow chart for a diesel engine for testing emissions (such as HC, CO NO_x and smoke) characteristics of biodiesel.

11. Conclusions

With continuous increase in energy demand and environmental concerns where most of the energy demands are met by fossil fuels, energy security has become the main priority for most economic development. As alternative renewable energy resources, biodiesel from neem, karanja, rubber and jatropha oils is becoming important worldwide. Most biodiesel missions focused on vegetable oil and some few other non-edible oils. But

in reality, diversifying the oil resources to include neem, karanja, rubber and jatropha as multipurpose non-edible tree plants will not only ensure sustainable and long-term supply of biodiesel feedstocks, will also contribute various advantages such as, environmental improvement, reclamation of waste lands, degraded forest medicinal, etc. to the economy. This is because neem, karanja, rubber and jatropha draw attention to their multiple uses (better pest and nutrient management, reforestation, medicinal purposes, environmental purification, etc.). Despite the existence

of several non-edible oils in many countries for biodiesel, the systematic study on these candidates (neem, karanja, rubber and jatropha) to fully develop them for sustainable agriculture and environment is essential. From the study, these four multipurpose non-edible tree plants (neem, karanja, rubber and jatropha) therefore show great potentials as non-edible biodiesel feedstock that can ensure sustainable bioenergy production.

Conflict of interest

The authors declare that there is no conflict of interest.

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