International Journal of Biological and Pharmaceutical Sciences Archive

ISSN: 0799-6616 (Online)
Journal homepage: https://ijbpsa.com/

(REVIEW ARTICLE)

Biodiesel production: An updated review of evidence

Ravindra B. Malabadi [1,*], Sadiya MR [2], Kiran P. Kolkar [3] and Raju K. Chalannavar [1]

[1] *Department of Applied Botany, Mangalore University, Mangalagangotri-574199, Mangalore, Karnataka State, India.*
[2] *Department of Biochemistry, JSS Medical college, Mysore- 570015, Karnataka State, India.*
[3] *Department of Botany, Karnatak Science College, Dharwad-580003, Karnataka State, India.*

International Journal of Biological and Pharmaceutical Sciences Archive, 2023, 06(02), 110–133

Publication history: Received on 25 September 2023; revised on 07 November 2023; accepted on 10 November 2022

Article DOI: https://doi.org/10.53771/ijbpsa.2023.6.2.0104

Abstract

This review paper highlights the production of biodiesel from different plant based feedstocks via the transesterification process. Biodiesel is a renewable, non-toxic, environment-friendly and an economically feasible option to tackle the depleting fossil fuels and its negative environmental impact. Biodiesel in general possess higher kinematic viscosity and density than conventional diesel. However, because of food security concerns, the use of edible oil in biodiesel production is criticized globally. Non-edible plant oils, waste cooking oils, and edible oil industry byproducts are suggested as effective biodiesel feedstocks because nonedible feedstock does not compete with food from human consumption. High-potential second-generation feedstock for biodiesel production uses waist cooking oil, acid oil, and animal tallow. Non edible crops in India as a feedstock for biodiesel production are yellow oleander oil (*Cascabela thevetia*), Pongamia (*Pongamia pinnata*), *Jatropha curcas*, Mahua (*Madhuca longifolia*), Candlenut (*Aleurites moluccanus*), Rubber (*Hevea brasiliensis*), Soapnut (*Sapindus mukorossi*), Jojoba (*Simmondsia chinensis*), Tobacco (*Nicotiana tabacum*), Neem (*Azadirachta indica*), Karanja (*Millettia pinnata*), Castor (*Ricinus communis*), Polanga (*Calophyllum inophyllum* L), Cotton (*Gossypium*), Kusum (*Carthamus tinctorius*), Yellow oleander (*Cascabela thevetia*), Sea mango (*Cerbera odollam*), Tung (*Vernicia fordii*), and Bottle tree (*Brachychiton rupestris*). Biodiesel is a sustainable liquid bio-energy resource that might be used to replace diesel fuel. Despite having numerous advantages over conventional diesel, the biodiesel industry is still struggling in India because of various reasons and challenges like availability, high feedstock pricing, operational hurdles, and supply-chain management challenges.

Keywords: Biodiesel; Castor oil; Feedstocks; Global warming; Hemp seed oil; India; Jatropha *curcas*; Non-edible oils; Transesterification

1. Introduction

Biodiesel is an alcoholic ester of various fatty acids, also known as FAME (Fatty Acid Methyl Esters) [1-151]. The biodiesel is the one of the fuel used in the CI engine. Biodiesel is synthesized from plant oil, agro-waste derived materials, lipids of microalgae, animal fat, and sewage sludge via the transesterification process [1-151]. Biodiesel is one of the current renewable and environment friendly energy sources capable of meeting energy demands [1-150]. Biodiesel is renewable, non-toxic, environment-friendly and an economically feasible options to tackle the depleting fossil fuels and its negative environmental impact [1-151]. In addition to being biodegradable, biodiesel emits fewer greenhouse gases than fossil diesel[1-151]. Moreover, biodiesel has high combustion efficiency and a reduced ignition delay time [1-60]. It can be used directly or blended with fossil diesel with minimal engine modification [1-151]. Due to these qualities, biodiesel has attracted the attention of the global scientific community, and numerous researchers are pursuing its development [20-60]. Biodiesel is promoted because of having low carbon contents compared to fossil fuels, thus reducing the emission of greenhouse gasses from automobiles [1-40-151]. High-potential second-generation feedstock for biodiesel production uses cooking oil, acid oil, and animal tallow. However, traditional fuel resources are depleting

---

[*] Corresponding author: Ravindra B. Malabadi

and fossil fuel produce more emission to the environment, which leads to harmful effects to the living organisms and affect the environment feasibility[1-151].

According to the literature survey on biofuels, the feedstocks used to produce biodiesel are, soybean oil (30%), rapeseed oil (25%), palm oil (18%), other plant seed oils (11%), waste cooking oil (WCOs) (10%), and fats (6%)[1-150]. However, because of food security concerns, the use of edible oil in biodiesel production is criticized globally. Non-edible plant oils, waste cooking oils, and edible oil industry byproducts are suggested as effective biodiesel feedstocks because nonedible feedstock does not compete with food from human consumption [1-151]. The biodiesel production from wildly growing nonedible feedstocks or waste cooking oil will be the least cost [1-40]. However, nowadays, the major feedstocks of biodiesel are edible oils and this has created food vs fuel debate. Therefore, the future prospect is to use non-edible oils, animal fats, waste oils and algae as feedstock for biodiesel [1-60]. Several nonedible plant oils, such as castor oil, jatropha oil, mahua oil, neem plant oil, pongamia oil, and yellow oleander oil, are currently used as feedstocks for biodiesel production [1-151]. Thus, the characteristics of biodiesel depend on the feedstock properties. Animal fats, coconut oil, palm oil, neem seed oil, tea seed oil, orange peel oil, papaya and watermelon seed oil, safflower oil, kapok seed oil (*Ceiba pentandra;* Malvaceae), mango seed oil, soapberry seed oil, grape seed oil, rubber seed oil, Karanja seed oil, flax seed oil, *Silybum marianum* L. seed oil**,** African pear (*Dacryodes edulis*) seed-oil**,** pequi seed oil, pumpkin seed oil, *Allanblackia floribunda* seed oil, soybean oils, sunflower oil, canola oil, flax seed oil*, Moringa oleifera***,** rapeseed oil, Camelina seed oil, *Dodonaea viscosa* oil, *Prosopis julifera* seed oil, rice bran oil, Pineapple (*Ananás comosus*) leaves, safflower oil**,** waste cooking oil, spent coffee grounds, soapberry seed oil, *Madhuca indica* oil, hemp seed oil, mustard oil, peanut oil, *Cucumis melo* var. agrestis seed oil*, Brassica nigra*, *Hura crepitans* seed oil*, Hibiscus sabdariffa* seed oil, *Phoenix dactylifera***,** cotton seed oil, castor oil, jatropha oil, microalgal lipids, juliflora oil, spent frying oils, pongamia plant oil, *Sisymbrium irio oil,* sewage sludge, soybean, *Helianthus annus*, waste cooking oils (WCOs), and yellow oleander are currently utilized as feedstocks for biodiesel [1-151].

There are different methods available for the preparation of the biodiesel. Among them, transesterification is one the easiest and best method to extract the biodiesel [1-19]. The shift from homogenous catalysts to heterogeneous catalysts for biodiesel production is the major break through in reducing the product cost [19, 20]. The catalytic efficacy and reusability are the properties which make the heterogeneous catalysts desirable in terms of product quality and cost [1-19]. According to the study conducted by Tata Energy Research Institute (TERI) in 2023[21-22], biodiesel production in India is currently under production with non-edible oilseeds, used cooking oil (UCO), animal tallow, acid oil, algal feedstock, etc [21-22]. The majority share is through non-edible sources, followed by UCOs and animal tallows [21-22]. Despite having numerous advantages over conventional diesel, the biodiesel industry is still struggling in India because of various reasons and challenges like availability and high feedstock pricing, operational hurdles, supply-chain management challenges [21-151].

Biodiesel production cost is higher as compared to conventional petroleum-based diesel fuel [1- 20]. Therefore, increments of biodiesel content in biodiesel–diesel fuel blends will result in rising fuel production costs[1- 40]. Furthermore, biodiesel content in biodiesel–diesel fuel increases, the overall calorific value per volume shall reduce due to biodiesels possessing lower calorific value (CV) than petroleum-based diesel[1-40]. This will lead to increased fuel consumption as more fuel will be consumed in order to produce the same amount of energy as conventional petroleum-based diesel[1-20]. Furthermore, fuel consumption could also increase as biodiesel possess higher viscosity which could lead to poor fuel pumping and spray behaviour [20-151]. Selection of non-expensive feedstock and the extraction and preparation of oil for biodiesel production is a crucial step due to its relevance on the overall technology [20-150]. There are three main conventional oil extraction methods: mechanical, chemical/solvent and enzymatic extraction methods [1- 22]. There are also some newly developed oil extraction methods that can be used separately or in combination with the conventional ones, to overcome some disadvantages of the conventional oil extraction methods [20-40].

Biodiesel in general possess higher kinematic viscosity and density than conventional diesel [1-22]. These factors affect fuel droplets atomization and entrainment when injected into the combustion chamber [1-22]. However, in a modern diesel engine equipped with a common rail fuel injection system, it is argued that the effects of the aforementioned properties were rather insignificant [1-40]. This is because, high pressure fuel injection introduced by the common rail fuel injection system enables improved fuel droplets atomization and evaporation, therefore enhancing combustion process [1-22]. Nonetheless, biodiesel emit higher nitrogen oxides (NOx) emissions when taking into account longer ignition delays caused by higher peak combustion temperatures as the result of higher oxygen content in biodiesel [1-22]. Furthermore, due to lower Calorific value (CV) of biodiesel, fuel consumption is considerably higher compared to conventional diesel [1-40]. Several research have documented higher fuel consumption when using various biodiesel blends in common rail injection diesel engines. In order to reduce NOx emissions and improve fuel consumption of biodiesel and biodiesel–diesel blends, there is a need to reduce in-cylinder temperatures and improve combustion efficiency[1-22]. One strategy to achieve this is by using Water-in-diesel (W/D) emulsion fuel [1-40]. The effects of W/D has been studied for many years and has shown promising improvements in terms of engine performance and exhaust emissions [1-40]. This can be attributed to micro-explosion of micro-sized water droplets dispersed in diesel oil [1-40]. But the problem is that water and oil could not be mixed naturally, synthesis of Water-in-diesel (W/D) emulsions required the use of a chemical additive known as surfactant or emulsifier to suspend the water particles in the diesel oil for a sustained period of time [1-40]. This review paper presents, compare and discusses different potential biofuel feedstocks, and proposed a future prospective for the sustainability of biodiesel production and utilization.

2. Biodiesel Production in India

India is one of the fastest growing economies in the world and energy security is critical for its socio-economic development [21, 22, 41]. India relies heavily on crude oil imports, and this trend will continue due to the rapid growth of its economy and over crowded population [21, 22, 41, 151]. India is the fourth-largest petroleum consumer in the world after China, the United States, and Russia [21, 22, 41]. The petroleum products consumption in India has increased about 38.2% from the past decade, resulting in a substantial expenditure on oil imports [21, 22, 41-150]. Indian Oil Corp and Reliance Industries have bought Venezuelan oil in the past. India is the world's third biggest oil importer and consumer and ships over 80% of its oil needs from overseas and wants to cut its crude import bill. Venezuela has one of the largest oil reserves and production from it at a large scale will have a dampening effect on global oil prices. India has a huge amount of on-road diesel consumption, and for success of the blending programme the availability of biodiesel becomes crucial [21-22]. According to TERI's estimates (TERI, 2021, 2023), overall energy demand from the transport sector may increase more than four-folds; between 2016 and 2050 [21, 22, 41, 151]. India aims to reduce its carbon footprint by 30–35% till 2030 [21, 22, 41]. In recent years, India has been the fastest- growing sector in terms of end-use and is already set for a huge expansion of transport infrastructure in every mode [21, 22, 41]. According to the TERI report [21, 22, 41], India's oil demand, as per Stated Policies Scenarios (STEPS), will rise by almost 4 million barrels per day (mb/d) to reach 8.7mb/d by the year 2040 [21, 22, 41]. As the domestic oil resources in India are limited, India imports large quantities of crude oil (the second largest importer) to meet the energy demands [21, 22, 41]. The country's dependence on imported oil is around 75% (IEA, 2021) and costs a massive foreign exchange investment [21, 22, 41]. Therefore, as a part of the Indian energy basket, biofuels have a strategic role to play [21, 22, 41].

Several initiatives have been introduced to increase indigenous production of biofuels, as part of the Indian government's aggressive plan of 20% ethanol in petrol by 2025–26 and 5% biodiesel in diesel by 2030 [21, 22, 41-150]. The country is still trying to develop a consistent supply chain for used cooking oil (UCO) [21, 22, 41]. Indian oil marketing companies (OMCs) failed to support biodiesel production in the informal sectors and demand continues to be inadequate [21, 22, 41]. Furthermore, a lack of feedstock supplies has prohibited market development [21, 22, 41]. According to TERI report, India's biodiesel production lacks sufficient production and supply from Oil Marketing Companies (OMCs) to build commercial sales. Hence, it is mostly consumed by locally dispersed groups to generate power [21, 22, 41, 151].

In India, the key drivers for sustainable and commercial production of biofuels are feedstock availability and production cost [21, 22, 41]. The implementation of India's biofuel blending program will be effective only if all stakeholders work together [21, 22, 41]. India is a very diverse country with immense potential for oil seeds cultivation [21, 22, 41]. Due to modernization and its dynamic economic growth, India's energy demand will continue to have a robust increase [21, 22, 41]. The number of vehicles on the road is increasing day-by-day, leading to an increase in fuel consumption [21, 22, 41]. Hydrocarbon fuel combustion contributes to the generation of carbon-based particles in the exhaust and pollutes the environment [21, 22, 41]. Compared to renewable biofuels, non-renewable fuels emit more hydrocarbons, nitrogen oxides, sulphur oxides, and carbon monoxide [21, 22, 41]. Increasing attention has been paid to renewable fuels to reduce pollution (by completing the carbon cycle) and reduce petroleum imports [1-21, 22, 41]. Considering the growing demand for fossil fuel and the rapidly growing motor vehicle fleet in India, the Government of India, New Delhi had set a target to reduce 10% oil imports by 2022 [21, 22, 41]. Currently, India has a limited variety of alternative fuel options for diesel vehicles and is in the initial stages of electrification [21, 22, 41]. The use of hydrogen fuel cells, battery operated vehicles, are in the commercialization phase; especially in medium and heavy-duty bus segments [21, 22, 41]. At the same time, the issue remains with availability and reliability of the prime energy source [21, 22, 41]. In this regard, biodiesel is the most prominent source and one of the relatively cleaner options in medium/heavy-duty vehicles: SUVs, taxis, buses, etc[1-21, 22- 45, 151].

In India, biodiesel is produced primarily from nonedible vegetable oil, acid oils, animal tallow, and palm stearin oil [1-45]. Domestically available used cooking oil (UCO) has been identified as a potential raw material for biodiesel production in the National Policy on Biofuels, 2018 [21, 22, 41]. The waste cooking oil can be collected in bulk from consumers such as restaurants, hotels, etc., for conversion into biodiesel [21, 22, 41]. Biodiesel in its pure form is termed B100, or neat biodiesel and can also be blended with conventional diesel as B56 and B20 [1-45]. Biodiesel production in the India is currently happening with non-edible oilseeds, used cooking oil (UCO), animal tallow, acid oil, algal feedstock, etc [21, 22, 41]. The majority share is through non-edible sources, followed by UCOs and animal tallows [21, 22, 41, 151].

Non-edible sources are some of the country's most promising sources of biodiesel production. National Policy on Biofuels, 2018 also promotes using non-edible sources like jatropha, karanja, mahua, etc., because of their growth potential, wasteland availability, yield, among other reasons [21, 22, 41-151]. Non edible crops in India as a feedstock for biodiesel production are *Jatropha curcas*, Mahua (*Madhuca longifolia*), Candlenut (*Aleurites moluccanus*), Rubber (*Hevea brasiliensis*), Soapnut (*Sapindus mukorossi*), Jojoba (*Simmondsia chinensis*), Tobacco (*Nicotiana tabacum*), Neem (*Azadirachta indica*), Karanja (*Millettia pinnata*), Castor (*Ricinus communis*), Polanga (*Calophyllum inophyllum* L), Cotton (*Gossypium*), Kusum (*Carthamus tinctorius*), Yellow oleander (*Cascabela thevetia*), Sea mango (*Cerbera odollam*), Tung (*Vernicia fordii*), and Bottle tree (*Brachychiton rupestris*) [21, 22-45-149]. Major challenges and barriers with the non-edible source are its current unavailability, improper cultivation, regularization, high polyunsaturated fatty acids, and low unsaturated fatty acid content, etc [21, 22-45]. However, this could be taken care of technological advancements [21, 22, 41]. Therefore, biodiesel significantly reduces the tailpipe emissions of carbon monoxide, unburned hydrocarbons, and other particulate matter, compared to conventional diesel and supports the environment [1-21, 22-45]. A major component of acid rain, sulphur dioxide and sulphates are virtually eliminated with biodiesel [1-21, 22-45].

High-potential second-generation feedstock for biodiesel production uses cooking oil, acid oil, and animal tallow[1-21, 22-45]. A high conversion and yield percent from raw material to biodiesel, cheap rates, and availability are some of the positives points for these feedstocks [1-21, 22-45]. The major barriers include the poor collection mechanism, disrupted supply-chain network, proper regulation mechanism, etc[1-21, 22-45]. Used cooking oil has been a potential feedstock in India because of its availability and high procurement[1-21, 22-45]. According to MOP&NG, India uses approximately 27 billion litres of cooking oil annually, of which about 1.4 billion litres of used oil could be collected from bulk users (restaurants, railways, etc.) to generate about 1.1 billion litres of biodiesel[1-21, 22-45]. Though the potential is very high, the supply-chain network, proper regulations in line, and other policy loopholes make achieving the target difficult [1-21, 22-45]. According to the study report of TERI (2021, 2023), and FSSAI, Government of India, estimated that the country generates around 2.7 million tonnes of UCO annually, about 60% of which renters the food chain, posing a serious threat to people's health[1-21, 22-45]. To make this used oil industry regularized and prevent UCO from re-entering the food chain, FSSAI took the initiative to form RUCO (Repurposed Used Cooking Oil), which also has several biodiesel manufacturers registered with them to facilitate the flow of UCO from the industry to the manufacturers[1-21, 22-45]. However, the industry still struggles with very low collection and supply chain management because of a lack of aggregators in tier 2 and 3 cities, smaller private collectors, diversion to the soap industries, etc [1-21, 22-45]. Animal tallow is yet another potential feedstock available in India for biodiesel production [1-21, 22-45]. The unorganized tallow industry makes it much more difficult. The scope of animal tallow is higher in north India, but with limited suppliers it becomes much more difficult to regularize this sector[1-21, 22-45].

There are few challenges associated with using biodiesel as fuel; 1) Due to its lower calorific value, the fuel consumption becomes higher. 2)NOx emissions are slightly higher than conventional diesel. 3)Biodiesel has a higher freezing point in comparison with diesel. 4) Biodiesel used in its pure form for a longer period of time can cause corrosion; especially if used without any coating, etc [1-21, 22-45]. As potential long-term solution, synthetics such as methanol to dimethyl ethers blended with diesel or a green diesel are recommended [1-21, 22-60]. Green diesel is made from the same feedstock as biodiesel (primarily animal fats and vegetable oils), but the production process differs considerably. Moreover, green diesel has the same chemical properties as regular diesel, so no engine modifications are necessary nor is necessary to change the existing infrastructure to distribute petroleum-based diesel [1-21, 22-60].

3. Biodiesel: Transesterification Reaction

Biodiesel is a sustainable liquid bio-energy resource that might be used to replace diesel fuel [1-151]. It has the potential to reduce pollutant emissions and may be used without modification in compression ignition engines [1-150]. As an alternative fuel, biodiesel possesses qualities that are comparable to diesel fuel [1-150]. Transesterification is the process of turning large, branching triglycerides into smaller, straight-chain methyl esters in the presence of a solvent, employing an alkali, acid, or enzyme as a catalyst [1-151]. Transesterification is the conversion of a carboxylic acid ester into a different carboxylic acid ester [1-151]. When an ester placed in a large excess of an alcohol along with presence of either an acid or a base, there can be an exchange of alkoxy groups. The large excess of alcohol is used to drive the reaction forward. The most common method of transesterification is the reaction of the ester with an alcohol in the presence of an acid catalyst. Conversion of one ester into another ester via exchange of -OR groups is called transesterification. The transesterification process aids in the reduction of oil viscosity [1-45]. In the presence of homogeneous catalysts such as sodium hydroxide (NaOH), potassium hydroxide (KOH), and sulphuric acid, the method works effectively [1-151]. Methanol and ethanol are the most often used solvents, with methanol being favored due to their inexpensive cost and physical and chemical properties [1-150]. They efficiently break down sodium hydroxide in these alcohols and react swiftly with triglycerides [1-150]. Transesterification requires a 3:1 stoichiometric molar ratio of alcohol to triglycerides [1-45]. To push the equilibrium to a maximum ester yield, the ratio must be greater in reality [1-151].

Biodiesel can be produced by conventional transesterification method, i.e. homogeneous, heterogeneous, and enzyme or advanced technology processes (microwave, ultrasound, or plasma assisted process) [150, 151]. Conventional transesterification processes are time-consuming and costly [1-60]. New methods, such as non-thermal plasma technology, reduce the reaction time and temperature [1-151]. Therefore, research studies aims to evaluate the use of a combined plasma jet–hydrodynamic reactor for transesterification [1-60]. The plasma jet used in this research comprised a ceramic tube with a central high-voltage electrode and a ring outer electrode, into which argon gas was fed [1-151]. Plasma technology in the field of chemical reactions is developing quite rapidly in addition to existing conventional technologies [150]. There is a significant difference between heating with plasma technology and heating with conventional technology[150]. In conventional heating, the required reaction temperature is quite high, whereas in plasma heating, the required temperature is quite low but can produce high energy electrons with a temperature of about 10^4 K [151]. Therefore, it is able to excite the components in the reactants. This is much different from conventional heating which has low energy in breaking bonds in the reactants [1-151]. Heating with plasma can significantly reduce the activation energy so that the reaction time can take place faster[150]. Plasma-assisted technology has several advantages compared with a conventional method, such as: shorter reaction time, no soap product, no glycerol product, and higher biodiesel yield [1-151].

4. Biodiesel Production: Case studies

4.1. *Sisymbrium irio* L seed oil

Biodiesel is one of the current renewable and green energy sources capable of meeting the future energy demand [1-150]. In one of the study, nonedible seed oil of *Sisymbrium irio L.* (*Brassicaceae* family) was used to produce biodiesel via a transesterification chemical reaction over a homemade TiO_2 catalyst [1]. *Sisymbrium irio L.* is widely available in Saudi Arabia, Iraq, America, Australia, South Africa, China, India and Japan [1]. According to this study, at 1:16 oil to methanol ratio, maximum 93% biodiesel yield was obtained over 20 mg catalyst concentration at 60° C for 60 min of reaction time [1]. According to this study, homemade TiO_2 nanoparticles are prepared by the hydrolysis of titanium isopropoxide precursor into $Ti(OH)_4$ and further dehydration of $Ti(OH)_4$ into TiO_2 [1].

The produced biodiesel has 3.72 mm2/ s kinetic viscosity (at 40°C), 0.874 kg/L density, – 4.3 °C cloud point and – 9.6°C pour point and 41.62 MJ/kg high heating value[1]. The quantitative and qualitative analysis was performed by FT-IR, GC-MS, and NMR spectroscopy [1]. GC-MS study confirmed 16 different types of fatty acids of methyl esters [1]. Further this study also confirmed that all these parameters fall within the specified range of ASTM D6751 test limit [1-60]. It has 0.42 mg KOH/mg/Kg acid value, 106 °C flash point, 0.034 water content, which are below the specified limit of ASTM D6751[1]. The low water content of biodiesel is an attractive feature in the mean of corrosion resistance [1-60]. The unsaturation degree of biodiesel is reflected by the iodine value [1]. The iodine value and oxidative stability are found at 131 and 3.15 h, respectively, which is above than ASTM D6751 test limit [1]. Due to the presence of more oxygen than conventional diesel, it has a lower calorific value (28,197 kJ/kg) [1-150]. The relatively lower cetane number (42) of biodiesel can be overcome by the addition of nitric acid and iso-cotyl [1]. This study confirmed that the physicochemical properties of *Sisymbrium irio* biodiesel (SIB) is an eco-friendly fuel and a competitive source for the commercial production of biodiesel [1-149]. The large-scale production of *Sisymbrium irio L.* for biodiesel feedstock is cost-effective [1]. Furthermore, the *Sisymbrium irio* biodiesel (SIB) is engine friendly and has good fuel efficacy [1-151].

4.2. Palm (*Elaeis guineensis)* seed oil

Malaysia is one of the leading exporters of palm oil and is able to produce its own palm oil biodiesel [43, 44]. Palm (*Elaeis guineensis) belongs to family Arecaceae*, cultivated as a source of oil. Palm oil, obtained from the fruits, is used in making soaps, cosmetics, candles, biofuels, and lubricating greases and in processing tinplate and coating iron plates [43, 44]. Palm kernel oil, from the seeds, is used in manufacturing such edible products as margarine, ice cream, chocolate confections, cookies, and bread, as well as many pharmaceuticals [43, 44]. However, as the European Union (EU) is becoming increasingly hostile towards palm oil imports, Malaysia utilized palm oil based biodiesel commodity in the domestic market [43, 44]. However, due to the oxygen-rich nature of biodiesel, its utilization suffers from increased nitrogen oxides (NOx) emission compared to conventional diesel [43]. One of the study attempted and investigated implementation of a real-time non-surfactant emulsion fuel supply system (RTES) which produces water-in-diesel emulsion as fuel without surfactants [43, 44]. NOx reducing capability of water-in-diesel produced by RTES has been well documented [43-149]. Therefore, in this study, 30% biodiesel–diesel (B30) was used as the base fuel while B30-derived emulsions consisting of 10 wt%, 15 wt% and 20 wt% water content were supplied into a 100 kVA, 5.9-L common rail turbocharged diesel engine electric generator [43, 44]. Fuel consumption and exhaust emissions were measured and compared with commercially available Malaysian low grade diesel fuel (D2M) [43]. Evidence suggested that emulsified B30 biodiesel–diesel produced by RTES was able to increase brake thermal efficiency (BTE) up to a maximum of 36% and reduced brake specific fuel consumption (BSFC) up to 8.70% [43]. Furthermore, B30 biodiesel–diesel emulsions produced significantly less NOx, carbon monoxide and smoke at high engine load [43, 44]. This study concluded that B30 biodiesel–diesel emulsions can be readily utilized in current diesel engines without compromising on performance and emissions [43, 44-151].

4.3. Indian soapberry (*Sapindus mukorossi*)

Indian soapberry (*Sapindus mukorossi*) is the one of the source for biodiesel production among the world [19-151]. The soapnut tree, which belongs to the family *Sapindaceae*, is one of the most economically important trees found in tropical and subtropical climates from Japan to India in Asia [19, 54]. Soapnut is known for its fruit, which contains triterpenoid saponins (10.1%) in the pericarp [19, 54]. Saponin is a natural detergent for washing the body, hair, and cloths, and it is used as natural detergent [19, 54]. *Sapindus mukorossi*, also known as Indian soapberry tree, is a deciduous perennial plant in the soapberry tree family, *Sapindaceae* [19, 54]. *Sapindus mukorossi* is native to western coastal India and southern China where it can be found growing in poor soil conditions and high altitudes [19, 54]. *Sapindus mukorossi* seed oil is commonly used as a source for biodiesel fuel [19, 54-150]. Its phytochemical composition is similar to the extracted oil from *Sapindus trifoliatus* seeds, which exhibit beneficial effects for skin wound healing [19, 54]. Since *S. mukorossi* seed shows no cyanogenic property, it could be a potential candidate for the treatment of skin wounds [19, 54].

One of the recent study investigated the diesel, biodiesel of soapberry seed and their 10% to 30% volume of blends (10BDSS, 20BDSS and 30BDSS) with diesel used in the CRDI engine [19]. The blends descriptions are: 10BDSS (10% BDSS + 90% diesel), 20BDSS (20% BDSS + 80% diesel), and 30BDSS (30% BDSS + 70% diesel) [19]. This work highlights the identification of the better performance results based biodiesel of soapberry seed blend with diesel, which have lesser emission results [19-149]. The blending of the biodiesel of soapberry seed (10% to 30%) produced from the transesterification process used CRDI engine at different load condition has been studied [19-149]. This study confirmed that blending of the biodiesel of soapberry seed usage in the CRDI engine is possible at different loads [19]. The percentage of biodiesel increase created the significant influence on the experimental results in combustion, performance and emission [19]. Diesel have maximum brake thermal efficiency (30.10%) than other blends [19]. The 30% biodiesel of soapberry seed (30BDSS) used blend have lowest peak cylinder pressure, lowest heat release rate in combustion than diesel [19]. Further this study reported that the 30% biodiesel of soapberry seed (30BDSS) used blend have lowest HC, CO and smoke emissions but NOx emission increased [19]. The 30BDSS blend created uppermost NOx emissions than other fuels[19-149]. 30BDSS have 27.82% of BTE, 1348 ppm of NOx emission, 78.93 bar of peak pressure, 61.15 J/deg of HRR with lesser CO (0.81%), HC (11 ppm) and smoke opacity (15.38%) emissions [19].

According to this study, soapberry seeds purchased in Chennai and dried in sunshine for 10 days[19]. The oil extracted by the tradition oil extraction such as cold press method. 72 kg of seed produced 32 lit of oil [19]. This raw oil was used to produce biodiesel by the transesterification process with methanol and KOH as a catalyst in the container with magnetic stirrer for 3 h with 65°C of operating temperature [19]. Then the 80% of biodiesel (BDSS—Biodiesel of Soapberry Seed) yield separated from glycerine after one day of cooling [19]. This oil is 10–30% with 10% of incrementally blended with diesel by volume for this investigation with CRDI engine [19]. 10BDSS is blend of 10%BDSS and 90% of diesel, 20BDSS is blend of 20%BDSS and 80% of diesel, and 30BDSS is blend of 30%BDSS and 70% of diesel were used in the experiment [19-151].

4.4. Industrial *Cannabis sativa* (Hemp)

The burning of fossil fuel is responsible for the current climate change, leading to the greenhouse gas emissions [1-151]. Furthermore, developing alternative renewable fuels improves energy security and decreases vulnerability of fuel supply [89-113, 151]. This is due to the fact that fossil fuel, a finite resource, is depleting at a rapid rate with increasing demand [89-151]. Biodiesel is a renewable energy alternative to fossil fuels that is composed of a group of long chain fatty acids called mono-alkyl esters [89-151]. It is a highly efficient diesel replacement that is produced by a process called transesterification, a chemical reaction between vegetable or animal fat and alcohol in the presence of a catalyst to produce biodiesel [1-113]. Unlike diesel produced from petroleum, it contains very low level of sulphur, which produces sulphur oxide (SOx) emissions when burned, a major precursor to acid rain [89-151].

Industrial hemp, a variant of the *Cannabis Sativa* plant (*Cannabis Sativa Linn*), is an important industrial and nutritional crop [65-113]. Hemp seed oil can be used to produce biodiesel though the process of transesterification [65-113]. Oil from hemp seeds presents a viable feedstock option for biodiesel production [89-113, 151]. Another important advantage is that biodiesel requires no modifications to the diesel engine[1-113-151]. Hemp biodiesel presents a carbon neutral replacement to diesel fuel [89-113]. The carbon dioxide emissions released to the atmosphere when burning biodiesel is reabsorbed through photosynthesis [89-113].

Hemp seed oil has a clear advantage over palm seed oil as a source of biodiesel fuel. Hemp can also be used as alternative to biodiesel production from palm oil [65-113, 151]. Hemp based biofuels present a viable, low emission replacement for petroleum-based fuels [89-149]. Biodiesel from hemp seed oil exhibits superior fuel quality with the exception of the kinetic viscosity and oxidation stability parameters, which can be improved with the introduction of chemical additives [89-113]. Hemp remains a "niche" crop in the food supply chain, which makes it prohibitively expensive a primary feedstock in biodiesel production [65-113, 151]. The quality of biodiesel depends on a range of characteristics such as heat value, specific gravity, flash point, sulphur content, viscosity, cloud point, pour point, oxidization stability, etc [89-113]. ASTM standard in the USA and Canada and EN 14214 in the EU defines minimum and maximum limits for these parameters[1-113]. As biodiesel use has become more widespread, engine manufacturers have expressed concerns with regards to biodiesels higher viscosity which could result in higher fuel injection pressure at low operating temperatures [89-113, 151]. However, biodiesel fuels have demonstrated temperature dependent behaviour similar to that of common diesel fuels[1-113]. Sulphur content is an important parameter as burning fuels containing higher sulphur content releases sulphur oxide compounds which are major pollutants and a leading cause of acid rain [1-113]. Biofuels in general have negligible sulphur content. Oxidation stability is an important indicator of long-term storage capability of the tested fuel [1-113-151].

Hemp is a cleaner fuel than soybean and rapeseed biodiesel fuels [89-113]. This is demonstrated by a significantly lower sulphur content [89-113]. It is also a safer fuel for handling, storage and transport due to its higher flash point [1-113]. However hemp biodiesel performs poorly when it comes to its kinematic viscosity which is slightly higher than the European EN 14214 max of 5 mm2/s but still lower the American ASTM D6751 maximum of 6mm2/s [1-113]. Furthermore, hemp biodiesel as well as other biodiesel exhibit poor oxidation stability compared to common diesel varieties and below the 6 and 8 hours specified by the ASTM D6751 and EN 14214 respectively [89-113]. These parameters can easily be improved with the chemical additives to satisfy testing specifications [89-113]. Antioxidants are often used to inhibit biodiesel oxidative degradation and increase the shelf life of the fuel [89-113]. Also, the higher viscosity of biodiesels can be improved by either blending it with petro-diesel or less saturated FAME, as well as the use of some additives [89-113, 151].

Biodiesel can be blended with petroleum diesel at different percentages [89-113-151]. The "B" factor is universally used to designate the percentage of biodiesel in the mix[1-113]. The most common of these blends are B100, B20, B5 and B2 which contain 20%, 5% and 2% respectively [89-113, 151]. Fuels are blended for various reasons such as environmental compliance [89-113]. B20 biodiesel blend is one of the most common blended fuels [89-151]. It is popular because it represents a good balance of improved performance, lower emissions, materials compatibility, cost and its ability to act as a solvent [89-149]. In the United States, most biodiesel users can purchase B20 biodiesel blends from the normal fuel distributors [89-113]. Additionally, biodiesel blends of 20% or lower do not require any modification to the diesel engine [89-151]. Biodiesel can also be used without blending (B100), however, certain modifications to the engine are required to avoid maintenance and performance issues [89-151].

B100 (Pure Biodiesel) contains 8% less energy content than its petroleum counterpart. Nevertheless, it can be used on some engines built after 1994 with biodiesel compatibility [1-113, 151]. On the other hand, biodiesel fuels exhibit superior engine cleaning effect since they act as solvents and can be used to clean the deposits accumulated in the engine due to petrol diesel use [89-151]. Hemp performs well in biodiesel blends [89-113, 151]. In one comparative study, it was found that hemp B20 blend provides better thermal efficiency, lower specific fuel consumption, reduced CO and CO_2 emissions in comparison to pure diesel and Jatropha B20 blends [89-151]. However, the hemp blend has a higher NOx emission in the study [89-151].

Industrial hemp has only a trace amount of THC, and its seeds are currently consumed in a variety of food products [65-113]. The perception and legal status of hemp need to be challenged to produce a positive influence in hemp related industries [65-113]. This remains the largest obstacle for a large scale hemp production [651-13]. However, in more recent years, many nations started revoking their ban on industrial hemp production, recognizing its great potential [65-113]. However, as the momentum to legalize hemp production is on the rise, the barriers could go up in flames [65-113]. Legal and perception challenges remain a major challenge in the way of wide-scale hemp biodiesel production [65-113]. Another major hurdle to spread biodiesel use is the required modification to the diesel engine when modifications manufacturers standards etc [89-113-151]. However, this is changing as the most recent diesel engines are made to be biodiesel compatible [1-113, 151]. There are also some technical and incentive barriers that contribute to hemp biodiesel production and biodiesel in general [89-113, 151]. One of these technical barrier is that higher blend rating requires engine modification to avoid performance and maintenance issues [89-113, 151].

Hemp oil has a great potential to be used as a primary feedstock, or in combination with other types of oil, in the production of biodiesel fuel [89-113]. It has not yet been produced on a commercial scale despite numerous studies indicating its advantages [65-113]. Hemp seeds present a viable feedstock option for biodiesel production [89-113]. Hemp biodiesel yield was calculated at 207 gallons/ha [89-113, 151]. This is higher than the yield of biodiesel from rapeseed and soybeans oils but lower than that of palm oil [89-113, 151]. Hemp biodiesel exhibit poor kinematic viscosity and oxidation stability [89-113, 151]. However, this can easily be improved with the use of additives [89-113, 151]. Hemp biodiesel performs well in biodiesel blends [89-113]. Hemp biodiesel provides substantial environmental benefits [89-113,151]. The amount of emission reduction corresponds roughly to the biodiesel blend rating of the fuel [89-113]. Hemp biodiesel may be used an alternative to the highly controversial biodiesel produced from palm oil [89-113, 151]. Hemp faces many perception and legal challenges that prevent wide-scale production of hemp seed oil [89-113, 151]. Legalization and increased production of hemp oil may improve the cost of producing hemp oil and subsequently hemp biodiesel [89-113, 151].

4.5. Industrial *Cannabis sativa* (Hemp)

Hemp seed oil is chosen as a feedstock for biodiesel production, methanol and KOH were used in the biodiesel production [89-113, 151]. The chemical and physical properties of hemp oil biodiesel are measured to investigate the engine emission and performance characteristics of diesel engine [89-113, 151]. The results of this study confirmed that B20 blend performance is best among other fuels tested [89-113, 151]. Besides, the Brake Specific Fuel consumption (BSFC) at full load (0.3 kg/kW h) for B20 is slightly lesser than diesel fuel (0.32 kg/kW h) [89-113]. This indicates that the lower diesel/hemp seed oil biodiesel blends will increase the performance as well as decrease the fuel consumption [89-113, 151]. Considering, the emissions from exhaust exhibited that Carbon Monoxide (CO), Hydrocarbon (HC) and Nitrox oxide (NOx) were lowered for all hemp seed oil biodiesel/diesel blends [89-113]. However, smoke emission increased slightly than diesel [89-113, 151]. In general, the results of this study concluded that hemp oil biodiesel is a best alternative as well as good substitute fuel to diesel[89-113]. The cannabis seed oil contains carbohydrates (20–30%), protein (20–25%), fibre (10–15%), and minerals such as calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), phosphorus (P), iron (Fe), and zinc (Zn) [89-113, 151]. A research study evaluated that the cannabis B20 blend provides lower fuel consumption, improved thermal efficiency, and lower CO and CO2 discharge than pure diesel and jatropha B20 blends. However, it has higher NOx emission efficiency, which is unsuitable for the environment [89-113, 151].

4.6. Industrial Cannabis sativa (Hemp)

Recent concerns regarding climate change and rising energy costs have dramatically increased interest in using alternative energies, especially biomass energy which is carbon neutral [1-151]. Hemp is among the fastest growing plants with unique fibre characteristics. Seven clones (KU03, KU18, KU27, KU45, KU49, RPF1, and RPF2) of four-month-old hemp (*Cannabis sativa*) were used in this work [96,151]. Physical properties, volatile content, fixed carbon, ash content, calorific value, chemical composition, ash composition, and metal element of the samples were investigated [96-113]. The results revealed that hemp stalk had desirable fuel characteristics with high volatile substance, high heating value, low ash content, very low nitrogen content, and non detectable sulphur [96]. Selecting well-adapted clones and appropriate technology which can convert the hemp stalks to suitable bioenergy forms are important aspects of bioresource management [96-113, 151]. Based on research finding of this study, some selected hemp clone biomass possessed excellent characteristics and great potential to be used as raw material for bioenergy production [96, 151].

The global cannabis (*Cannabis sativa*) market was 17.7 billion in 2019 and is expected to reach up to 40.6 billion by 2024 [96-113, 151]. On the other hand, greenhouse gas emissions and the rising demand for petroleum-based fuels pose a severe threat to the environment and the circular economy[1-113, 151]. Cannabis biomass can be used as a feedstock to produce various biofuels and biochemicals [65-113, 151]. Various research groups have reported production of ethanol 9.2–20.2 g/L, hydrogen 13.5 mmol/L, lipids 53.3%, biogas 12%, and biochar 34.6% from Cannabis biomass [89-96]. Biodiesel can be primarily produced from hemp seed oil [89-113, 151]. Hemp seed comprises 25%–35% oil high in fatty acids [65-96]. The oil is usually used in foods. However, the composition makes it promising for biodiesel [65-96]. Biofuels from hemp seed oil exhibit superior fuel quality because of low sulphur content and high flash point [89-113]. However, hemp biodiesel performs poorly regarding its kinematic viscosity and poor oxidation stability, which can be resolved by introducing chemical additives like antioxidants [96, 151].

4.7. Industrial *Cannabis sativa* (Hemp)

Hemp is a short-rotation crop with a high yield [95-97, 151]. It can produce up to 20 tons/hectare of dry biomass per cropping season under favourable conditions [95-97]. Due to its rapid growth and production, it is one of the most effective CO_2 biomass converters [95-97, 151]. Hemp is an excellent carbon capturer which can absorb more CO_2 per hectare than most agricultural commodity crops and perhaps even woods. Hemp can absorb up to 22 tons of CO_2 per hectare [95-97, 151].

4.8. Industrial *Cannabis sativa* (Hemp)

Hemp stalks do not contain sulphur which is a definite advantage over fossil fuels[95-97]. The existence of sulphur in fuels is undesirable due to sulphur dioxide gas release during combustion[1-97]. Sulphur dioxide gas can react with water to form sulphuric acid clouds, a critical component of the planets global atmospheric sulphur cycle and contributes to global warming [1-151]. Hemp has the potential to be a sustainable renewable resource for bioenergy, reducing the dependency on fossil fuels, which harm the environment due to polluting the air and environment during their production and use, causing the depletion of the ozone level, one of the leading causes of climatic changes and global warming and minimizing the emissions of greenhouse gases [89-150]. Hemp stalks showed desirable fuel characteristics with other bioenergy feedstocks, such as high heating value, low ash content, high volatile substance, very low nitrogen content, and do not contain sulphur [89-113-151]. It appears that hemp stalks would have good potential as bioenergy. However, selecting well-adapted clones and appropriate technology which can improve the fuel properties of hemp stalks are needed [95-97, 151].

4.9. Industrial *Cannabis sativa* (Hemp)

Cannabis sativa Linn, known as industrial hemp, was utilized for biodiesel production [89-113, 151]. Oil from hemp seed was converted to biodiesel through base-catalyzed transesterification [89-113]. The conversion is greater than 99.5% while the product yield is 97% [89-113, 151]. Several ASTM tests for biodiesel quality were implemented on the biodiesel product, including acid number, sulphur content, flash point, kinematic viscosity, and free and total glycerin content[1-87, 89-113, 151]. In addition, the biodiesel has a low cloud point and kinematic viscosity (3.48 mm^2/s) [89-113, 151]. This may be attributed to the high content of poly-unsaturated fatty acid of hemp seed oil and its unique 3:1 ratio of linoleic to a-linolenic acid [89-113, 151].

4.10. Papaya and watermelon seed oil

Asokan et al., 2018 [114] reported biodiesel from papaya and watermelon seed oil by trans-esterification process using methanol and KOH as catalyst [114]. A new biodiesel i.e. WP is produced which is a mixture of papaya seed oil based biodiesel and watermelon seed oil biodiesel in a 1:1 ratio is prepared [114]. The blends (B0, B20, B30, B40, and B100) of WP with diesel, watermelon 100% and papaya 100% are used for further testing [114]. The performance, combustion and emission test were conducted on single cylinder 4-stroke diesel engine using different blends of these biodiesels and the results showed that B20 is superior blend among other biodiesel blends [114]. Further, the performance and combustion characteristics of B20 is very close to diesel while the emission characteristics of B20 is better than that of diesel as the emission of CO, HC and smoke is 27.27%, 23.8%, 8.3% less for B20 than diesel respectively [114-149]. Thus this study concluded that B20 is the most suitable blend of WP for substitute of diesel which will reduce diesel consumption by 20% [114-151].

4.11. *Prosopis juliflra* seed Oil

Another investigation by Asokan et al., (2019) [115] on biodiesel produced from *Prosopis juliflora* seeds using the 2-stage acid transesterification process followed by alkali transesterification process producing 80% yield of Juliflra Oil Methyl Ester has been reported [115]. Experiments were conducted on single cylinder diesel engine using juliflora biodiesel and its diesel blends [115]. The experimental results of fuel blends (B20, B30, B40, and B100) were compared with those from diesel (D100) [115]. The results indicated the performance and combustion characteristics of B20 as almost in line with those of diesel fuel trend [115]. Brake Specific Fuel Consumption (BSFC) for blends B20 and B30 (0.27kg/KWh) at full load was closer to diesel (0.26 kg/KWh) [115]. The BTE for *Prosopis* juliflora biodiesel B100 is 31.11% and it was closer to diesel (32.05%) at full load [115-149]. However, the emission characteristics of CO, HC and smoke for biodiesel and its blends were smaller or equal compared to diesel throughout the experiment [115]. At full load, the NOx for biodiesel B100 was 1832 ppm which was a little higher than diesel fuel (1821 ppm) [115-149]. This has led to the conclusion of B20 being the most suitable blend of other blends and it is substitute of diesel which will reduce diesel consumption by 20% [115-151].

4.12. *Jatropha curcas* seed oil

Jatropha curcas is a genus of around 175 succulent shrubs and trees in the *Euphorbiaceae* family (some of which are deciduous, such as *Jatropha curcas* L.) [9, 12, 16, 25, 116, 117,118]. It is a drought-tolerant perennial that thrives in poor or marginal soil and produces a large amount of oil per hectare [9, 12, 16, 25, 116, 117,118]. It is easy to grow, has a fast growth rate, and can generate seeds for up to 50 years [9, 12, 16, 25, 116, 117,118]. *Jatropha curcas* has been developed as a unique and promising tropical plant for augmenting renewable energy sources due to its various benefits [9, 12, 16, 25, 116, 117,118]. It is deserving of being recognized as the only competitor in terms of concrete and intangible environmental advantages [9, 12, 16, 25, 116, 117,118]. *Jatropha curcas* is a low-cost biodiesel feedstock with good fuel properties and more oil than other species. It is a non-edible oilseed feedstock [9, 12, 16, 25, 116, 117, 118]. *Jatropha curcas* emits fewer pollutants than diesel and may be used in diesel engines with equivalent performance [9, 12, 16, 25, 116, 117,118]. *Jatropha curcas* also makes a substantial contribution to the betterment of rural life. The plant may also provide up to 40% oil yield per seed based on weight [9, 12, 16, 25, 116, 117,118]. The use of *Jatropha curcas* as a biodiesel feedstock has exploded in popularity in recent years [9, 12, 16, 25, 116, 117,118]. It is a tropical plant that may be grown as a commercial crop or as a hedge to protect fields from grazing animals and prevent erosion in low to high rainfall areas [9, 12, 16, 25, 116, 117,118]. The properties and performance of biodiesel made from *Jatropha curcas* were examined and reported [9, 12, 16, 25, 116, 117,118]. In terms of raw resources, *Jatropha curcas* based biodiesel does not compete with human food because of the existence of certain harmful components, non-edible plant oils are not acceptable for human consumption, according to tests conducted around the world and findings available in the literature [9, 12, 16, 25, 116, 117,118].

Jatropha curcas plants, unlike other food plants, do not need rich soil. These plants are widely accessible in underdeveloped nations, and they are particularly cost effective when compared to edible plant oils [9, 12, 16, 25, 116, 117,118-150]. When utilized in an internal combustion engine, Jatropha-based biodiesel produces less pollution[9, 12, 16, 25, 116, 117,118]. The engine performance of Jatropha biodiesel is equivalent to that of petroleum-based diesel [9, 12, 16, 25, 116, 117,118-150]. Good economic performance and necessary public policies are essential components in achieving commercial *Jatropha curcas* based biodiesel manufacturing success [9, 12, 16, 25, 116, 117,118]. However, *Jatropha* biodiesel is made through a simple triglyceride and fatty oil transesterification process that is aided by alkaline or acidic catalytic agents [9, 12, 16, 25, 116, 117,118-151]. The latter has a number of drawbacks; researchers have looked for enzymes that are less harmful to the environment [9, 12, 16, 25, 116, 117,118]. Because fossil fuel (coal, oil, and gas) reserves are fast depleting, it is predicted that Jatropha-based biodiesel will be a viable long-term alternative [9, 12, 16, 25, 116, 117,118-150]. These fossil fuel resources are limited, if they are used over an extended period of time, global resources will ultimately run out [9, 12, 16, 25, 116, 117,118]. To summarize, the Jatropha is differentiated by the many ecological, energy, and economic advantages connected with its commercial usage, and increased use of this plant is helpful to the environment and food production [9, 12, 16, 25, 116, 117,118-151].

4.13. Dodonaea (*Dodonaea viscosa* Jacq.) seed oil

Traditional energy supplies such as natural gas, coal, and petroleum currently meet the increasing global energy demand, but these resources are rapidly decreasing and are at the point of extinction[1-150]. The primary sources of electricity are petroleum-based fuels such as oil, coal, and natural gas[1-151]. However, as humanity reliance on fossil fuels has grown, the rate of asset exhaustion and the threat of global warming have also increased [1-151]. As a result, alternative fuels must be developed to reduce fossil fuel consumption, while also reducing greenhouse gas emissions [1-150]. In this circumstance, biomass derivative fuels, which are renewable, sustainable, and environmentally benign, may be a superior option[1-151]. Biodiesel plays a key role in reducing greenhouse gas emissions in the transportation sector[1-151].

Dodonaea (*Dodonaea viscosa* Jacq.) belongs to the family *Sapindaceae* [119]. It is an evergreen shrub or small tree that grows throughout the tropics and subtropics of the world from the coast to an altitude of more than 2000 m. It is an Australian native, but it can also be found in India, Pakistan, New Zealand, Mexico, Florida, Africa, the Virginia Islands, Arizona, and South America[119]. The therapeutic benefits of Dodonaea are well-known. The locals utilize its leaves, blossoms, and roots to treat a number of ailments, including skin infections, fever, pain, swelling, diarrhea, toothache, and headache [119]. In India, it is used as a wood fuel source, and the seeds are used as a fish poison [119]. According to the literature survey the seeds contain 20.23% fixed oil, [119]. However, due to their **poisonous** nature, they are not used for cooking or other purposes[119]. Dodonaea oil has been proposed for biodiesel production[119]. According to Bukhari et., (2022) [119], Dodonaea oil was studied as a potential biodiesel source [119]. Dodonaea (*Dodonaea viscosa* Jacq.) is an evergreen shrubby plant that thrives in tropical and subtropical conditions [119]. The plant produces high-grade biodiesel in terms of both quantity and quality despite its naturally high fat content [119]. In the transesterification followed by esterification reaction, varied ratios of oil to methanol, constant temperature (60°), reaction duration (1h), and different catalyst concentrations (0.25–0.75% (w/w) were utilized [1-119, 151]. A maximum biodiesel yield of 90% was achieved [119]. For fuel characteristic analysis, the prepared biodiesel was specified and compared to ASTM criteria [119]. The chemical composition was verified using analytical techniques such as FT-IR and NMR spectroscopy[119]. As a result of the foregoing, Dodonaea is considered as a possible bioenergy source, particularly in the transport sector [119].

Bukhari et., (2022) [119] reported the biodiesel made from Dodonaea crude oil using the alkaline transesterification mechanism[119]. For the transesterification procedure, a 250-mL conical flask, a multiple heating magnetic stirrer, and a thermometer were used [119]. On a hot plate, the filtered oil was heated to 120°C to remove any moisture and then cooled to 60°C [119]. KOH was dissolved in methanol and stirred for 30–35 min to produce methoxide [119]. At 60° C, methoxide was added to the oil and swirled for 60 min [119]. The mixture was allowed to settle for 8–10 hrs or overnight at room temperature after an hour [119]. Three lyres were discovered in the end. In the base of crude biodiesel, a gelatinous material known as glycerin was produced in the shape of tiny spots floating on the surface [119]. The lyres were isolated using simple handling devices. The crude biodiesel was rinsed in warm water to remove the contaminants[119]. The method was performed two to three times to remove all the contaminants. Anhydrous sodium sulphate was added after washing to remove any leftover moisture[119]. The biodiesel was distilled after purifying it and rotated at 55° C for 1 h to remove any extra methanol [119].

Bukhari et., (2022) [119], experimental study reported that a number of transesterification processes were carried out with the changing oil-to-methanol molar ratios, different kinds of catalyst concentrations, reaction time, and temperature to determine the best conditions for the maximum conversion of oil to biodiesel [119]. The process of the transesterification reaction was carried out in a 1/2 litre three-necked round-bottom flask equipped with a sampling outlet, reflux condenser, thermometer, and magnetic stirrer [119]. Approximately, 250 ml dodonaea filtered oil was heated. The temperature was maintained up to 120° C for 1 h [119]. The moisture and degraded mono, di-glyceride were removed from the acylglycerole [119]. The transesterification reaction of dodonaea oil was carried out with various oil molar ratios and catalyst concentrations (w/w) [119]. The temperature (60°C), reaction time (2 h), and stirring velocity (600 rpm) were kept constant for the reactions [119]. The resultant product after the complete reaction was allowed to cool down at room temperature[119]. The upper phase contained a thin spot of soap and the middle part biodiesel, while the base phase contained a gelatinous mass of glycerin, and the mixture was separated by simple decantation [119].

In the end, the mixture was separated into two layers: the upper layer contain dodonaea crude biodiesel having an excess amount of methanol [119]. The crude biodiesel was purified by residual methanol distillation at 65°C for 60 min by a moderate rotary evaporator[119]. The remaining catalyst together with other inorganic impurities formed soap, and some catalyst was removed by consecutive washing steps with distilled water by adding three to four drops of weak acid (CH_3COOH) to neutralize the remaining catalyst [119]. The extra water molecule was removed with the help of anhydrous sodium sulfate (Na_2SO_4) followed by filtration [119].

According to the current study by Bukhari et., (2022) [119] on Dodonaea plant oil, this plant provides a promising and innovative source for biodiesel manufacturing [119]. On the basis of this study, the biodiesel output was reported to be 90% [119]. A 1:6 M oil-to-alcohol ratio, a temperature of 600°C, a reaction period of 70 min, and a concentration of 0.25% potassium hydroxide catalyst was used [119]. The fuel characteristics of the Dodonaea plant biodiesel were analyzed and compared to the American Society for Testing and Materials standards [119-150]. Dodonaea plant oil is nonedible and a promising source for biodiesel production, based on the fuel qualities and physico-chemical analyses outlined previously [119-151].

4.14. *Cucumis melo* var. agrestis, small gourd or musk melon seed oil

Cucumis melo var. agrestis, small gourd or musk melon, is an annual or perennial herbaceous climbing vine that belongs to the family *Cucurbitaceae* and is found all over the old-world tropics [120]. This study examined the potentiality of non-edible seed oil (*Cucumis melo* var. agrestis) content 29.1%, FFA 0.64 (mg KOH/g) for biodiesel production via nanocatalyst [120]. The catalyst was characterized using X-ray diffraction spectroscopy (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDX) [120]. The maximum biodiesel yield (93%) was attained under optimized conditions, i.e., 9:1 methanol to oil molar ratio, 2 wt% catalyst (MgO) at 60°C [120]. The synthesized biodiesel yield was optimized through response surface technology via Box Behnken design (BBD) [120]. Biodiesel was characterized by advanced analytical techniques, including gas chromatography and mass spectroscopy, FTIR, and nuclear magnetic resonance (NMR) [120-150]. Fuel properties of synthesized biodiesel, including density (0.800 kg/L), K. viscosity @ 40°C (4.23 cSt), cloud point −12°C, pour point −7°C, sulphur content (0.0001%), flash point (73.5°C), total acid no (0.167 mg KOH/g) were found in lines with international standard of American Society of Testing Materials (ASTM) [120-150]. *Cucumis melo* var. agrestic seed oil and nano MgO catalyst appeared as economical, sustainable, and feasible candidates to overcome global energy glitches and environmental issues[120]. This study findings involving unpalatable seed oil will be a promising step toward non-food biomass biorefinery [120].

Biodiesel or fatty acids methyl esters (FAMEs) are produced via transesterification of fats and oils (triglycerides) using methanol in the presence of suitable catalysts like homogeneous catalysts such as acids and bases (H_2SO_4, HCl, KOH, and NaOH), heterogeneous catalyst such as bases (Alkali metals, and Alkaline earth metal-based catalyst, mixed metal-based, transition metal-based, Hydrotalcite-based, waste-based catalysts), acids (Cation exchange resins, heteropolyacid derivatives, sulfated oxide based and sulphonic acid-based catalysts), acid/base catalyst (Zirconia, and zeolite-based), biocatalysts like enzymes, and nano-catalysts (CaO/CuFe2O4, $MgO/MgAl_2O_4$, and $Cs/Al/Fe_3O_4$) [1-151]. In general, biodiesel is produced at the industrial level via homogeneous catalysts[1-150]. However, such catalysts offer higher yields yet are coupled with several demerits (difficulty of neutralization, excessive methanol requirement, washing and drying for removal of glycerol and catalyst leading to wastage of water and rise in product cost) [120-151]. In contrast, green heterogeneous catalysts are attaining considerable attention for their potential competency in overcoming the shortcomings of homogeneous catalysts in biodiesel synthesis [1-150]. Heterogeneous nano-catalysts have gained popularity among researchers for the efficient conversion of oils to biodiesel owing to their high conversion rate, catalytic efficiency, good rigidity, large surface area, and great resistance to saponification [120-151].

Nanoparticles are pseudo-spherical and <100 nm in diameter, involved in enhancing reaction rate by lowering the activation energy of reactants so that they can be readily converted into products [120-151]. Various nano-catalysts have been experienced to synthesize biodiesel, such as $K_2O/c\text{-}Al_2O_3$ $KF/C\text{-}Al_2O_3$, Fe_3O_4 amorphous alumina, $Cs\text{-}Ca/SiO_2\text{-}TiO_2$, and potassium bitartrate with zirconia [120-151]. In addition, nano-catalysts are recoverable, green, i.e., environment-friendly, non-corrosive, and no post-treatment washing is required [120-151]. Alkali-based catalysts offer relatively higher conversion efficiency than acid catalysts among heterogeneous solid catalysts [120-151]. Because they have a large surface area (compared to bulky substances), stable rigor, pronounced confrontation to saponification, and high catalytic efficiency. Hence, they are considered more active catalysts during transesterification reactions [120-151].

4.15. *Phoenix dactylifera* (date palm) seed oil

Biodiesel is considered to be more friendly to the environment than petroleum-based fuels, cheaper and capable for producing greener energy which contributed positively in boosting bioeconomy[1- 151]. Because the main barrier to biodiesel consumption is its high price, there are numerous complications to making it effective and affordable [1-151]. To address such situations, researchers are focusing on the discovery and identification of novel non-edible oil-rich species that could serve as an efficient feedstock for biodiesel production [121-122]. Compared with fossil-derived fuels, the biodiesel generated from biomass is more biodegradable, recyclable and sustainable, and offers a high energy performance [121-151]. Its immediate usage as engine or generator fuel without additional processing has been demonstrated, indicating that this forms a promising source of fuel [1-150]. Different techniques, including pyrolysis, micro-emulsion, transesterification and dilution can be used to make biodiesel [1- 121-151]. Biodiesel is fatty acid methyl ester (FAME) that is commonly produced by transesterification process of different source of biomass such as animal fat, vegetable oil as jatropha oil, sunflower oil, cottonseed oil, soybean oil, palm oil, peanut oil, rapeseed oil and corn oil, and waste products such as waste cooking oil with alcohol in the presence of a catalyst[1-151]. The feasibility of a number of readily available non-comestible feedstocks has been shown in relation to biodiesel synthesis; examples include animal fat, rubber seed, palm kernel shell, date pit oil and jatropha oil, amongst others [1-121-151].

The *Phoenix dactylifera* (date palm) is the main tree grown in Saudi Arabia [121]. Date seeds are part of the waste produced by numerous industries that process dates [121]. Direct or indirect methods can be used to gather enormous quantities of date seeds from homes, date processing facilities, and businesses [121]. A new non-edible feedstock utilized from date seed oil was analyzed for the synthesis of eco-friendly biodiesel using newly novel hydroxyapatite heterogeneous catalysts, obtaining from waste camel bones prepared from dried camel bone followed calcination under different temperature [121-151]. This catalyst was characterized by X-ray diffraction (XRD), Brunauer–Emmett–Teller (BET) and transmission electron microscopy (TEM) [121]. Results showed that hydroxyapatite catalyst pore size reduced with increasing the calcination temperature [121]. Optimizied biodiesel yield (89 wt%) was achieved through the process of transesterification with optimum reaction conditions of 4 wt % catalyst, oil to ethanol molar ratio of 1:7 and temperature 75℃ for 3 h reaction time [121]. The production of FAME was confirmed by using gas chromatography-mass spectroscopy (GC–MS) [121-151]. Fuel properties of fatty acid ethyl ester complied with ASTM D 6751 which indicated that it would be an appropriate alternative form of fuel [121]. As a result, using biodiesel made from waste and untamed resources to develop and implement a more sustainable and environmentally friendly energy strategy is commendable [121]. The acceptance and implementation of the green energy method may result in favourable environmental effects, which in turn may lead to better societal and economic growth for biodiesel industry at a larger scale [121-151].

4.16. Six Non-edible Plant Sources

Biodiesel produced from non-edible plant sources is cost-effective, biodegradable, environment friendly, and compatible with petro-diesel, but new sources and extraction processes still need to be discovered [1-151]. One of the study conducted by Khan et al., (2021) [122] explored the fuel properties of seeds from six non-edible plant sources, including *Sapindus mukorossi* (Soapnut, SP), *Vernicia fordii* (Tung, TO), *Ricinus communis* (Castor, CA), *Toona sinensis* (Juss. TS), *Ailanthus altissima* (Heaven tree, AA), and *Linum usitatissimum* L. (Lin seed, LS) from China [122]. The optimum extraction conditions were obtained by optimizing the most important variables (reaction temperature, ratio of alcohol to vegetable oil, catalyst, mixing intensity, and purity of reactants) that influence the transesterification reaction of the biodiesel [122]. All six plants contained high seed oil content (SOC; % w/v) with the highest in the TO-54.4% followed by SP-51%, CA-48%, LS-45%, AA-38%, and TS-35%, respectively, and all expressed satisfactory physico-chemical properties as per international standards of ASTM D6751 and EN14214 [122]. The experimental data provided a scientific basis for growing these plants in unproductive agricultural lands as an alternative energy sources for biodiesel production either stand alone or blended with petro-diesel [122-151].

4.17. Grape seed oil

With increases in fuel prices worldwide and concerns for environmental pollution, the need for alternative sources of energy is becoming urgent [1-151]. In this study, the potential of grape seed oil for biodiesel as an alternative fuel was evaluated [123]. Refined grape seed oil was bought in liquid form and then subjected to an alkali-catalyzed transesterification process for biodiesel production [123]. The physicochemical properties of the resulting biodiesel namely, viscosity, cetane number, and heating value were investigated [123]. The biodiesel was blended with a conventional diesel in various proportions and combusted in a four-cylinder, four-stroke compression ignition (diesel) engine under two loading conditions [123, 124]. Experimental results revealed that the blend ratio of B70 (70% GS biodiesel and 30% conventional diesel) gave the best overall engine performance in terms of maximum power, minimum emissions, and fuel consumption [123]. Furthermore, a novel neural network technique called extreme learning machine was adopted to investigate the optimal blend ratio using the dataset obtained from the experimental results[123, 124]. The results also indicated that the best choice of biodiesel blend ratio is approximately B73.67 (73.67% GS biodiesel and 26.33% conventional diesel) [123]. This study confirmed that grape seed oil could serve as a reliable source of production of quality biodiesel fuels, which could be used as an alternative to conventional diesel fuels [123].

Owing to the performance of biodiesel produced from grape seed oil when tested using a four-cylinder, four-stroke compression ignition (diesel)-engine-powered vehicle, grape seed oil has been demonstrated to be a good potential biodiesel [123-151]. The properties of the biodiesel and its blends with conventional diesel were investigated and tested on a diesel vehicle [123]. The experimental results showed that, among the various biodiesel blends tested, B70 (70% GS-30% DI) has the lowest NOx emissions and medium levels of other emissions, and if horsepower, fuel economy, and emissions are considered with some weights, B70 remains the best choice [123-151]. Furthermore, the results obtained from this study also confirmed that the blend ratio B73.67 (73.67% GS-26.33 DI) has the best performance[123]. Therefore, the biodiesel from grape seed oil holds great potential, and can substitute for conventional diesel both in pure biodiesel form and in blends as fuel for diesel vehicles [123-151].

4.18. *Jatropha curcas* and Neem seed oil

This study investigated the production of biodiesel from non edible oil seeds of *Jatropha curcas* and neem [9, 12, 16, 25, 116, 117,118, 123, 124]. This is with a view to compare which of the oils when used for biodiesel production is more environment friendly and cheaper [25, 123, 124]. The optimum reaction time for transesterification of *Jatropha curcas* oil to biodiesel was recorded to be 3h while that of neem oil to biodiesel was 2h [9, 12, 16, 25, 116, 117,118, 123, 124]. This reduces the operating cost of neem biodiesel [25, 116, 123, 124]. Fatty acid methyl esters (FAME) yield of 86.61% with a viscosity of 5.64 cSt was obtained for Jatropha biodiesel using the established operating conditions [9, 12, 16, 25, 116, 117,118, 123, 124]. This viscosity was used as an index for maximum conversion of biodiesel (BD) for neem oil [25, 123, 124]. The viscosity obtained for neem oil biodiesel was 5.51cSt [9, 12, 16, 25, 116, 117,118, 123, 124-150]. According to this study, an attempt to increase the reaction time does not give any significant difference in the viscosity [25]. Experimental investigations of the different blends of biodiesel from the two oils were tested on an internal combustion engine [9, 12, 16, 25, 116, 117,118, 123, 124-151]. The emissions of different blends showed that neem biodiesel has lower emissions of CO and NOX than Jatropha biodiesel, but CO emissions of Jatropha biodiesel are lower than that of diesel fuel [9, 12, 16, 25, 116, 117,118, 123, 124]. The NOX value of petrol diesel is higher than B10– B50 and B10 – B80 of Jatropha and neem biodiesel respectively [9, 12, 16, 25, 116, 117,118, 123, 124-151]. However, NOX values of B60 – B100 and B90–B100 of Jatropha and neem biodiesel are in the range of 5.27 – 10.74% and 1.39– 11.93% higher than petrol diesel respectively [9, 12, 16, 25, 116, 117,118, 123, 124]. The physical properties of both biodiesel met the ASTM standard of D-6751 [9, 12, 25, 116, 123, 124-151].

4.19. Microalgae (*Chlorella vulgaris*) and Castor seed oil

The diminishing reserves and environmental consequences of the fossil fuel-based petrodiesel necessitated the exploration of an alternative fuel with better quality and minimum environmental impacts [1-151]. This study explored the optimization of biodiesel production from non-food, locally available mixed feedstocks as an effective, a sustainable approach to solve the insufficiency and high costs of single oil feedstock [1-125].The selection of suitable oil feedstocks and optimization of process variables are the prime issues for cost-effective industrial scale production of biodiesel from mixed feedstocks toward the industrial scale production of biodiesel [125-151]. This study optimized the process variables for the alkaline transesterication of mixed castor seed and microalgae oils and the yield of biodiesel was estimated [125]. Oils were extracted from dried microalgae (*Chlorella vulgaris*) biomass and castor seed kernel using methanol [125]. The oils were purified, characterized, mixed in a 1 :1 ratio, and converted to biodiesel [125]. The transesterication experiments designed according to the central composite design (CCD) were used to optimize the yield of biodiesel through the response surface methodology (RSM) [125]. Experimental results were analyzed by response surface regression to produce a model for predicting biodiesel yield [125-151]. Model significance, fitness, the effect of significant variables, and interactions between the variables on the yield of biodiesel were studied through the analysis of variance (ANOVA) [125]. The optimization of transesterication process variables revealed that the catalyst concentration of 1.23% (w/w), ethanol to mixed oil ratio of 5.94 :1 (v/v), and reaction temperature of 51.0°C were the optimum conditions to achieve an optimum biodiesel yield of 92.88% [125-151]. Validation experiments conducted under the optimum conditions resulted in the biodiesel yield of 92.36%, which is very close to the model predicted value[125]. Various standard methods were used to characterize the biodiesel produced under optimum conditions, and it was found compatible with ASTM 751 and EN14214 biodiesel standards [125-151].

4.20. Mango (*Magnifera indica*) seed oil

Feedstock costs accounts for the larger percentage of biodiesel production cost. The use of less expensive feedstock and optimization of the process variables that affect the yield presents the opportunity of significantly reduction of this cost[1-151]. One of the study investigated the effect of temperature and catalyst concentration on the transesterification of Mango (*Magnifera indica*) seed oil with methanol using potassium hydroxide as catalyst [126]. The biodiesel produced was characterized to ascertain its suitability for use as fuel [126-151]. Results obtained showed that increase in temperature results in corresponding increase in the biodiesel yield [126-151]. A yield of 83% wt was obtained at an optimum temperature of 60^o C [126]. A similar trend was observed on the effect of catalyst concentration, with the optimum being 80 % wt at 1% w/v[126]. Analysis of the biodiesel produced showed consistency with the threshold standard values quoted by ASTM and EN for biodiesel and fossil diesel [126-150]. This signifies that the biodiesel produced from mango seed oil is of good quality and can be used to consolidate the fossil based diesel [126-151].

4.21. Rubber (*Hevea brasiliensis*) seed oil

Rubber (*Hevea brasiliensis*) is economically cultivated for the production of latex as a source of natural rubber for the production of various rubber products in use globally, while the seeds are underutilized [127]. However, the oil from the seed is the second most valuable product after the latex [127]. The cultivation of rubber tree to generate latex for natural rubber production, and the utilization of its seeds to produce non-edible oil for biodiesel production will boost the economy of most African countries that are poverty-ridden [127-151]. Studies have shown that rubber seed contains 35– 45 % oil, which portrays a better competitor to other non-edible oil bearing plants in biodiesel production [127]. According to this study, non-edible vegetable oils from underutilized Nigerian NIG800 clonal rubber seeds were extracted from 0.5 mm kernel particle size using n-hexane as solvent to obtain a yield of 43 wt.% over an extraction time of 1 h [127]. The rubber seed oil was characterized for fatty acids by using gas chromatography-mass spectrometry (GC-MS), and for structural properties by Fourier transform-infrared (FT-IR) and nuclear magnetic resonance (NMR) analyses [127]. The optimum conditions obtained using RSM were: reaction time (60 min), methanol/oil ratio (0.20 vol/vol), and catalyst loading (2.5 g) with biodiesel yield of 83.11% which was validated experimentally as 83.06±0.013% [127]. Whereas, those obtained via ANN were reaction time (56.7 min), methanol/oil ratio (0.21 vol/vol), and catalyst loading (2.2 g) with a biodiesel yield of 85.07%, which was validated experimentally as 85.03±0.013% [127]. The characterized biodiesel complied with ASTM D 6751 and EN 14214 biodiesel standards was used in modern diesel test engine without technical modifications [1-127-151]. This biodiesel has a lower energy content compared with conventional diesel fuel, in all the cases of blends considered, the optimal engine speed for higher performance and lower emissions was observed at 2500 rpm [127-151]. Therefore, this study confirmed that, the B20 blend of rubber seed oil has best engine performance with a lower emission profile, and was closely followed by B50 blend [127-151].

4.22. Tea seeds oil (TSO)

Biodiesel seems to be one of the feasible alternative fuel with all the requisite characteristics for partial or total substitution of diesel fuel [1-150]. In this regard, one of this study reported the feasibility of producing biodiesel from **Tea seeds oil** (TSO) [128-150]. Tea, being a major plantation crop of Assam, its seeds are abundantly available in the region [128]. The transesterification of tea seed oil with methanol was done in the presence of potassium hydroxide (KOH) as a catalyst and the resulting tea seed biodiesel (TSB) was characterized by ^{1}H NMR and FTIR analysis [128-151]. The biodiesel produced was also tested for its fuel properties, diesel engine performance and emission characteristics as well as its rheological behaviour [128]. The fuel properties of TSB met both ASTM D6751 and EN 14214 biodiesel standard and were found comparable to biodiesel from other non-edible oil containing feedstocks [128-150]. The rheological behaviour of TSB and its blends with petro diesel exhibit near Newtonian behaviour [128]. The engine performance and emission characteristics showed that TSB can be used in diesel engine without any engine modification [1-151].

4.23. *Hibiscus sabdariffa* seed oil

Considerable interest is being focused on vegetable oils as fuel [1-151]. Due to their characteristics being close to diesel and their renewable potential, studies recommend their use for agricultural applications [1-129]. *Hibiscus sabdariffa* var. *sabdariffa* is widely studied for the nutritional properties of its calyces [129]. Although the seeds of this species are known to be rich in fatty acids, their use is little known in Benin Republic[129]. By following standard methods, the fatty acid profiles of oils extracted from the seeds of the two varieties (red phenotype, sabdariffa (HSS), and green phenotype, altissima (HSA)) of *H. sabdariffa* L. were established [129]. A comparative study of their physicochemical properties was also performed to highlight their potential use as fuel [129]. According to this study HSS seed oil is yellow while HSA seed oil is dark green[129]. This study confirmed that for these two varieties, values obtained for the kinematic viscosity (~4 mm2 /s), cetane number (~55), and density (0.87 g/cm3) are in accordance with the U.S. and European standards [129]. However, it is observed that HSA oil is significantly more acidic (23.10 ± 0.22 for HSS vs 18.20 ± 0.40 mg KOH/g oil for HSS) with a higher peroxide value (HSA: 0.280 ± 0.002 vs HSS: 0.140 ± 0.001) [129]. The major fatty acids are : palmitic (HSA: 27.09 vs HSS: 25.48%), oleic (HSA: 31.81 vs HSS: 35.21%), and linoleic (HSA: 31.43 vs HSS: 29.70%) acids[129]. This study confirmed that the fatty acid profiles of two oils calorific values (~39.45 MJ/kg) are lower than that of diesel but good oxidative stability and cold filter plugging [129]. The two oils could be used as fuel oil, after their transesterification to improve their properties[129-151].

4.24. African pear (*Dacryodes edulis*) seed-oil

Viability of African pear (*Dacryodes edulis*) seed-oil as a potential feedstock for biodiesel was examined in this work [130]. The yield of the extracted oil was 59% of the total seed [130]. Gas-chromatographic analysis of the oil extract showed that the oil was predominantly constituted by mono-unsaturated fatty acid (oleic acid, 76%) while the total percentage of its saturated fatty acids was 24% (palmitic acid, 6.1%; stearic acid, 7.5% and others, 10.4%) [130]. Pre-treatment of the oil extract with 1% w/w H_2SO_4 showed tremendous reduction in the free fatty acid from 12.33±0.05 to 0.10±0.02 mg KOH/g[130]. Biodiesel yield of the seed oil attained optimum yields at the methanol/oil molar ratio of 7:1, catalyst concentration of 1.00%, reaction temperature of 60°C, agitation speed of 850 rpm and effective contact time of 120 min[130-150]. However, the yields of the biodiesel were higher at these experimental conditions with homogeneous KOH catalyst than its NaOH counterpart [130-150]. Fuel properties such as smoke point, flash point, fire point, viscosity and specific gravity exhibited by the biodiesel of African pear (*Dacryodes edulis*) were found comparable with those of the petrol-diesel, and the values also fell within the acceptable limits of ASTM and EN standards [130-151].

4.25. Algal Resources

One of the recent study focused on the optimization of the energy conversion process and the use of algal resources for biodiesel production with ultrasound and microwave techniques for the first time in *Oedogonium, Oscillatoria, Ulothrix, Chlorella, Cladophora*, and *Spirogyra* [131-151]. The fuel properties were investigated to optimize the efficiency of the newly emerging algal energy feedstock [131]. This study indicated that the optimized microwave technique improved the lipid extraction efficiency in *Oedogonium, Oscillatoria, Ulothrix, Chlorella, Cladophora,* and *Spirogyra* (38.5, 34, 55, 48, 40, and 33%, respectively) [131]. Moreover, the ultrasonic technique was also effective in extracting more lipids from *Oedogonium* sp., *Oscillatoria* sp., *Ulothrix* sp., *Chlorella, Cladophora* sp., and *Spirogyra* sp (32, 21, 51, 40, and 36%, respectively) than from controls, using an ultra-sonication power of 80 kHz with an 8-min extraction time [131]. The fatty acid composition, especially the contents of C16:0 and C18:1, were also enhanced after the microwave and sonication pre-treatments in algal species [131]. Enhancement of the lipids extracted from algal species improved the cetane number, high heating value, cold filter plugging point, and oxidative stability as compared to controls [131-150]. The results of this study confirmed that the conversion of biofuels from algae could be increased by the ultrasound and microwave techniques, to develop an eco-green and sustainable environment [1-131].

4.26. *Jatropha curcas* seed oil

With the growing demand for vegetable oils, alternative non-edible feedstocks like *Jatropha curcas* seed oil have gained interest for biodiesel production[1-151]. This study comprehensively evaluated the physicochemical properties and biodiesel production potentiality of locally produced *J. curcas* seeds in Pakistan [9, 12, 16, 25, 116, 117,118, 123, 124-131]. According to this study, two different approaches were applied: A chemical synthesis approach involving acidic pretreatment and alkaline transesterification, and a biosynthetic approach using a lipase-producing strain of the *Bacillus subtilis* Q5 strain [9, 12, 16, 25, 116, 117,118, 123, 124-131]. The microbial biosynthesized biodiesel was further optimized using the Plackett–Burman design [9, 12, 16, 25, 116, 117,118, 123, 124]. The physicochemical properties of the *J. curcas* methyl esters were analyzed to assess their suitability as biodiesel fuel [9, 12, 16, 25, 116, 117,118, 123, 124]. Initially, the raw oil had a high free fatty acid content of 13.11%, which was significantly reduced to 1.2% using sulphuric acid pre-treatment, keeping the oil to methanol molar ratio to be 1:12[9, 12, 16, 25, 116, 117,118, 123, 124-131]. Afterward, alkaline transesterification of purified acid-pre-treated seed oil resulted in 96% biodiesel yield at an oil to methanol molar ratio of 1:6, agitation of 600 revolutions per minute (RPM), temperature 60°C, and time 2h [9, 12, 16, 25, 116, 117,118, 123, 124-131]. Moreover, alkaline transesterification yielded ~98% biodiesel at the optimized conditions: oil to methanol molar ratio 1:6, KOH 1%, time 90 min, and temperature 60°C [9, 12, 16, 25, 116, 117,118, 123, 124]. Similarly, the *Bacillus subtilis* Q5 strain yielded ~98% biodiesel at the optimized conditions: oil: methanol ratio of 1:9, agitation 150 RPM, inoculum size 10%, temperature 37°C, and n-hexane 10% [9, 12, 16, 25, 116, 117,118, 123, 124-131]. The fuel properties of *J. curcas* seed biodiesel are closely related to standard values specified by the American Society for Testing and Materials (ASTM D6751–20a) indicating its potential as a viable biodiesel fuel source [9, 12, 16, 25, 116, 117,118, 123, 124-131].

4.27. Soapberry Seed oil

Due to the ongoing demand for alternative fuels for CI engines, biodiesel-based research has received support globally [1-150]. In this study, soapberry seed oil via transesterifcation process produced biodiesel [1-132]. It is referred to as BDSS (Biodiesel of Soapberry Seed) [132]. According to criteria, the oil qualities are recognized, hence, three different blends and pure diesel were tested in CRDI (Common Rail Direct Injection) engines [132-149]. The blends descriptions are: 10BDSS (10% BDSS+ 90% diesel), 20BDSS (20% BDSS+ 80% diesel), and 30BDSS (30% BDSS+ 70% diesel) [132]. The outcomes of the related tests for combustion, performance, and pollution were contrasted with those achieved using 100% diesel fuel [132]. In this case, the mixing has resulted in worse braking thermal efficiency than diesel and lower residual emissions with greater NOx emissions [132]. This study confirmed that the superior results were obtained by 30BDSS, which had BTE of 27.82%, NOx emissions of 1348 ppm, peak pressure of 78.93 bar, heat release rate (HRR) of 61.15 J/ deg, emissions of CO (0.81%), HC (11 ppm), and smoke opacity of 15.38% [132].

4.28. Camelina or False flax [*Camelina sativa* (L.) seed oil

Camelina or false flax [*Camelina sativa* (L.) Crantz] is gaining attention throughout world for its ability to produce oil suitable for many applications such as lubricants, fuel additives, jet fuel, and biodiesel [133-151]. Camelina is an oilseed crop with favourable potential for biodiesel production and Camelina lines with improved oil yield and composition are being generated [133]. Biodiesel from Camelina will lead to energy security, stronger economy and improvement through bio-refineries producing biodiesel are on the way [133-151]. Genomic resources and genetic engineering platforms are available for sustainable Camelina oil production [133]. Camelina is an important oil crop with a fast-developing genetic platform for utilization in the production of designer lipids [133]. Camelina oil is used as a transport fuel as it is or converted into biodiesel by alcoholysis reaction with/without the presence of catalysts [133]. The overall process of biodiesel production from Camelina oil involves camelina cultivation, harvesting, seed processing to recover the oil, and the meal. The transesterification of camelina oil in the presence of a catalyst produced biodiesel and glycerol [133-151].The separation of crude biodiesel from glycerol, and crude biodiesel purification to obtain the final product satisfying the quality standard specification [133-151].

5. Conclusion

Biodiesel is renewable, non-toxic, environment-friendly and an economically feasible options to tackle the depleting fossil fuels and its negative environmental impact. In addition to being biodegradable, biodiesel emits fewer greenhouse gases than fossil diesel. Biodiesel is promoted because of having low carbon contents compared to fossil fuels, thus reducing the emission of greenhouse gasses from automobiles. However, traditional fuel resources are depleting and fossil fuel produce more emission to the environment, which leads to harmful effects to the living organisms and affect the environment feasibility. However, because of food security concerns, the use of edible oil in biodiesel production is criticized globally. Non-edible plant oils, waste cooking oils, and edible oil industry byproducts are suggested as effective biodiesel feedstocks because nonedible feedstock does not compete with food from human consumption. Several nonedible plant oils, such as castor oil, jatropha oil, mahua oil, neem plant oil, pongamia oil, and yellow oleander oil, are currently used as feedstocks for biodiesel production. There are different methods available for the preparation of the biodiesel. Among them, transesterification is one the easiest and best method to extract the biodiesel. In India, biodiesel is produced primarily from nonedible vegetable oil, acid oils, animal tallow, and palm stearin oil. Despite having numerous advantages over conventional diesel, the biodiesel industry is still struggling in India because of various reasons and challenges like availability and high feedstock pricing, operational hurdles, and supply-chain management challenges.

Compliance with ethical standards

Acknowledgments

We would like to thank and acknowledge, Karen Viviana Castaño Coronado, Chief Communications Officer (CCO) and CO-Founder of **LAIHA** (Latin American Industrial Hemp Association), and CEO- CANNACONS, Bogota, D.C., Capital District, Colombia for thoughtful discussions, critical comments, supporting, promoting, encouraging and appreciating this research work. We also thank all the members of LAIHA for supporting and encouraging this research work.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Ahmad Jan H, Osman AI, Al-Fatesh AS, Almutairi G, Surina I, Raja Al-Otaibi L Al-Zaqri N, Kumar R, Rooney DW. Biodiesel production from Sisymbrium irio as a potential novel biomass waste feedstock using homemade titania catalyst. Scientifc Reports. 2023; 13:11282.

[2] Basumatary S, Nath B, Kalita P. Application of agro-waste derived materials as heterogeneous base catalysts for biodiesel synthesis. J. Renew. Sustain. Energy. 2018; 10: 043105.

[3] Nath B, Das B, Kalita P, Basumatary S. Waste to value addition: Utilization of waste Brassica nigra plant derived novel green heterogeneous base catalyst for effective synthesis of biodiesel. J. Clean. Prod. 2019; 239: 118112.

[4] Brahma S. et al. Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. Chem. Eng. J. Adv. 2022; 10: 100284.

[5] Bohlouli A, Mahdavian L. Catalysts used in biodiesel production: A review. Biofuels. 2021; 12: 885–898.

[6] Jamil F. et al. Biodiesel production by valorizing waste Phoenix dactylifera L. Kernel oil in the presence of synthesized heterogeneous metallic oxide catalyst (Mn@MgO-ZrO2). Energy Convers. Manag. 2018; 155: 128–137.

[7] Naylor RL, Higgins MM. The rise in global biodiesel production: Implications for food security. Glob. Food Sec. 2018;16: 75–84.

[8] Zhang Y, Wong WT, Yung KF. One-step production of biodiesel from rice bran oil catalyzed by chlorosulfonic acid modified zirconia via simultaneous esterification and transesterification. Biores. Technol. 2013; 147: 59–64.

[9] Bojan SG, Durairaj SK. Producing biodiesel from high free fatty acid Jatropha curcas oil by a two step method-an indian case study. J. Sustain. Energy Environ. 2012; 3:63–66.

[10] De Barros, S. et al. Pineapple (Ananás comosus) leaves ash as a solid base catalyst for biodiesel synthesis. Bioresour. Technol. 2020; 312: 123569.

[11] Phan AN, Phan TM. Biodiesel production from waste cooking oils. Fuel. 2008; 87: 3490–3496.

[12] Teo SH. et al. Efficient biodiesel production from Jatropha curcus using CaSO4/ Fe2O3-SiO2 core-shell magnetic nanoparticles. J. Clean. Prod. 2019; 208: 816–826.

[13] Mathiyazhagan M, Ganapathi A. Factors affecting biodiesel production. Res. Plant Biol. 2011; 1: 1–5.

[14] Samanta S, Sahoo RR. Waste cooking (palm) oil as an economical source of biodiesel production for alternative green fuel and efficient lubricant. BioEnergy Res. 2021; 14: 163–174.

[15] Fadhil AB, Ahmed KM, Dheyab MM. Silybum marianum L. seed oil: A novel feedstock for biodiesel production. Arab. J. Chem. 2017; 10: S683–S690.

[16] Joshi A, Singhal P, Bachheti RK. Physicochemical characterization of seed oil of Jatropha curcus L. from Dehradun (Uttarakhand) Indian. J. Appl. Biol. Pharm. Technol. 2011; 2: 1237.

[17] Birla A, Singh B, Upadhyay SN, Sharma YC. Kinetics studies of synthesis of biodiesel from waste frying oil using a heterogeneous catalyst derived from snail shell. Biores. Technol. 2012; 106: 95–100.

[18] Gebremariam SN, Marchetti JM. Economics of biodiesel production: Review. Energy Convers. Manag. 2018; 168: 74–84.

[19] Sajjad AMO, Sathish T, Rajasimman M, Praveenkumar TR. Experimental evaluation of soapberry seed oil biodiesel performance in CRDI diesel engine. Scientific Reports. 2023; 13:5699.

[20] Keneni YG, Marchetti JM. Oil extraction from plant seeds for biodiesel production. AIMS Energy. 2017; 5(2): 316-340. DOI: 10.3934/energy.2017.2.316.

[21] TERI. Decarbonization of transport sectoring India: Present status and Future pathway. 2021;New Delhi: TERI.

[22] Jamal F, Qamar S, Prakash S, Rao IV. Accelerating Biodiesel Blending in India. New Delhi: The Energy and Resources Institute (TERI). 2023. Darbari Seth Block, India Habitat Centre, Lodhi, Road, New Delhi – 110 003, India

[23] Tang Y, Meng M, Zhang J, Lu Y. Efficient preparation of biodiesel from rapeseed oil over modified CaO. Appl. Energy. 2011; 88: 2735–2739.

[24] Vazquez VA. et al. Transesterification of nonedible castor oil (Ricinus communis L.) from Mexico for biodiesel production: A physicochemical characterization Transesterification of nonedible castor oil (Ricinus communis L.) from. Biofuels. 2020; 0:1–10.

[25] Kaisan MU. et al. Calorific value, flash point and cetane number of biodiesel from cotton, jatropha and neem binary and multiblends with diesel. Biofuels. 2017; 0: 1–7.

[26] Refaat AA, Attia NK, Sibak HA, El Sheltawy ST, ElDiwani GI. Production optimization and quality assessment of biodiesel from waste vegetable oil. Int. J. Environ. Sci. Technol. 2008; 5: 75–82.

[27] Mofijur M. et al. Effect of biodiesel-diesel blending on physico-chemical properties of biodiesel produced from Moringa oleifera. Procedia Eng. 2015; 105: 665–669.

[28] Kumar N. Oxidative stability of biodiesel: Causes, effects and prevention. Fuel. 2017; 190: 328–350.

[29] Sales-cruz M, Lugo-m H, Lugo-leyte R, Torres-aldaco A, Olivares-hern R. Synthesis of biodiesel from coconut oil and characterization of its blends. Fuel. 2021; 295: 120.

[30] Rahman W, Mondal AK, Hasan S, Sultan M. Biodiesel production from a non-edible source of royna (Aphanamixis polystachya) oil. Energy, Sustainability and Society. 2022; 12:33. https://doi.org/10.1186/s13705-022-00360-6

[31] Demirbas A. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: A survey. Energy Convers. Manag. 2003; 44: 2093–2109.

[32] Sivaramakrishnan K. Determination of higher heating value of biodiesels. Int. J. Eng. Sci. Technol. 2011; 3:7981–7987.

[33] Anand K, Ranjan A, Mehta PS. Estimating the viscosity of vegetable oil and biodiesel fuels. Energy Fuels. 2010; 24: 664–672.

[34] Adewuyi A, Awolade PO, Oderinde RA. Hura crepitans seed oil: An alternative feedstock for biodiesel production. J. Fuels. 2014: 1–8.

[35] Taylor P, Demirba A. Energy Sources, Part A: Recovery, utilization, and environmental effects production of biodiesel from algae oils Production of Biodiesel from Algae Oils. 2008; 37–41.

[36] Atabani AE. et al. Integrated valorization of waste cooking oil and spent coffee grounds for biodiesel production: Blending with higher alcohols, FT–IR, TGA, DSC and NMR characterizations. Fuel. 2019; 244: 419–430.

[37] Soon LB, Rus AZM, Hasan S. Continuous biodiesel production using ultrasound clamp. International Journal of Automotive and Mechanical Engineering (IJAME). 2013; 9: 1396–1405.

[38] Taufiq-Yap YH, Abdullah NF, Basri M. Biodiesel production via transesterification of palm oil using NaOH/Al2O3 catalysts. Sains Malay. 2011; 40(6): 587–594.

[39] Naoh U, Catalysts AO, Biodiesel P, Pengtransesteran M, Sawit M. Biodiesel production via transesterification of palm oil. Fuel. 2011; 40:587–594.

[40] Al-Mawali KS. et al. Life cycle assessment of biodiesel production utilising waste date seed oil and a novel magnetic catalyst: A circular bioeconomy approach. Renew. Energy. 2021; 170: 832–846.

[41] **Malabadi RB**, Kolkar KP, Chalannavar RK. Sweet Sorghum for Biofuel energy: Grain sorghum for Food and Fodder-Phytochemistry and Health benefits. International Journal of Innovation Scientific Research and Review. 2022; 4(9): 3305-3323.

[42] Samani AM, Samani BH, Ghasemi-Varnamkhasti M, Rostami S, Ebrahimi R. Biodiesel production from sunflower oil using a combined atmospheric cold plasma jet-hydrodynamic reactor. Biofuels. 2023; 14:9: 895-905.

[43] Tamam MQ, Omi MRT, Yahya WJ. et al. Engine performance and emissions evaluation of surfactant-free B30 biodiesel–diesel/water emulsion as alternative fuel. Scientifc Reports. 2023; 13: 10599.

[44] Hamasaki K, Kinoshita E, Matsuo Y, Jazair W. Utilization of palm oil for diesel fuel. Trans. Japan Soc. Mech. Eng. 2002; 68(667): 322–327.

[45] Elumalai PV, Parthasarathy M, Hariharan V, Jayakar J, Mohammed Iqbal S. Evaluation of water emulsion in biodiesel for engine performance and emission characteristics. J. Therm. Anal. Calorim. 2022; 147(6), 4285–4301.

[46] Debnath BK, Saha UK, Sahoo N. A comprehensive review on the application of emulsions as an alternative fuel for diesel engines. Renew. Sustain. Energy Rev. 2015; 42: 196–211.

[47] Vellaiyan S. Combustion, performance and emission evaluation of a diesel engine fueled with soybean biodiesel and its water blends. Energy. 2020; 201: 117633.

[48] Elkelawy M. et al. Maximization of biodiesel production from sunflower and soybean oils and prediction of diesel engine performance and emission characteristics through response surface methodology. Fuel. 2020; 266:117072.

[49] Keneni YG, Marchetti JM. Oil extraction from plant seeds for biodiesel production. AIMS Energy. 2017; 5(2): 316-340. DOI: 10.3934/energy.2017.2.316.

[50] Tamam MQ. et al. Performance and emission studies of a common rail turbocharged diesel electric generator fuelled with emulsifier free water/diesel emulsion. Energy. 2023; 268: 126704.

[51] Abdollahi M. et al. Impact of water–biodiesel–diesel nano-emulsion fuel on performance parameters and diesel engine emission. Fuel. 2020; 280: 118576.

[52] Mondal PK, Mandal BK. A comprehensive review on the feasibility of using water emulsified diesel as a CI engine fuel. Fuel. 2019; 237: 937–960.

[53] Gorski K. Experimental investigation of diesel engine powered with fuel microemulsion. Adv. Sci. Technol. Res. J. 2020; 14(2): 41–48.

[54] Chen CC, Nien CJ, Chen LG, Huang KY, Chang WJ, Huang HM. Effects of Sapindus mukorossi seed oil on skin wound healing: In vivo and in vitro testing. Int. J. Mol. Sci. 2019; 20: 2579; doi: 10.3390/ijms20102579.

[55] Ramesh Babu A. et al. Experimental investigation on the performance and emission characteristics of CI engine using waste cotton seed biodiesel with ZNO as a fuel additive. Int. J. Ambient Energy. 2020; 41(6): 669–673.

[56] Brahma S. et al. Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. Chem. Eng. J. Adv. 2022; 10: 100284.

[57] Muthukumaran C. et al. Process optimization and kinetic modeling of biodiesel production using non-edible Madhuca indica oil. Fuel. 2017; 195: 217–225.

[58] Moradi G, Ghanadi T. An experimental investigation of direct biodiesel production from castor seed using waste resource as economical catalyst. Environ. Prog. Sustain. Energy. 2019; 38(5): 13180.

[59] Duda K. et al. Comparison of performance and emissions of a CRDI diesel engine fuelled with biodiesel of different origin. Fuel. 2018; 212: 202–22.

[60] Ravikumar J, Saravanan S. Performance and emission analysis on blends of diesel, restaurant yellow grease and n-pentanol in direct-injection diesel engine. Environ. Sci. Pollut. Res. 2016; 24(6): 5381–5390.

[61] Sathish T. et al. Enhanced waste cooking oil biodiesel with Al2O3 and MWCNT for CI engines. Fuel. 2023; 333(2), 126429.

[62] Devarajan Y, Nagappan B, Subbiah G. A comprehensive study on emission and performance characteristics of a diesel engine fueled with nanoparticle-blended biodiesel. Environ. Sci. Pollut. Res. 2019; 26(11): 10662–10672.

[63] Wu G, Jian G, Yang Z, Huang Z. Emission characteristics for waste cooking oil biodiesel blend in a marine diesel propulsion engine. Pol. J. Gov. Stud. 2019; 28: 2911–292.

[64] Patil V, Thirumalini S. Effect of cooled EGR on performance and emission characteristics of diesel engine with diesel and diesel-karanja blend. Mater. Today Proc 2021; 46: 4720–4727.

[65] **Malabadi RB**, Kolkar KP, Chalannavar RK. Cannabis sativa: Ethnobotany and phytochemistry. International Journal of Innovation Scientific Research and Review. 2023; 5(2): 3990-3998.

[66] **Malabadi RB**, Kolkar KP, Acharya M, Chalannavar RK. Cannabis sativa: Medicinal plant with 1000 molecules of pharmaceutical interest. International Journal of Innovation Scientific Research and Review. 2023; 5(2):3999-4005.

[67] **Malabadi RB**, Kolkar KP, Chalannavar RK. Cannabis sativa: Industrial hemp (fiber type)- An Ayurvedic traditional herbal medicine. International Journal of Innovation Scientific Research and Review. 2023; 5 (2): 4040-4046.

[68] Malabadi RB, Kolkar KP, Chalannavar RK. Medical Cannabis sativa (Marijuana or Drug type); The story of discovery of Δ9-Tetrahydrocannabinol (THC). International Journal of Innovation Scientific Research and Review. 2023; 5 (3):4134-4143.

[69] Malabadi RB, Kolkar KP, Chalannavar RK. Δ9-Tetrahydrocannabinol (THC): The major psychoactive component is of botanical origin. International Journal of Innovation Scientific Research and Review. 2023; 5(3): 4177-4184.

[70] Malabadi RB, Kolkar KP, Chalannavar RK. Cannabis sativa: Industrial Hemp (fibre-type)- An emerging opportunity for India. International Journal of Research and Scientific Innovations (IJRSI). 2023; X (3):01-9.

[71] Malabadi RB, Kolkar KP, Chalannavar RK. Industrial Cannabis sativa (Hemp fiber type): Hempcrete-A plant based eco-friendly building construction material. International Journal of Research and Innovations in Applied Sciences (IJRIAS). 2023; 8(3): 67-78.

[72] Malabadi RB, Kolkar KP, Chalannavar RK, Lavanya L, Abdi G. Cannabis sativa: The difference between Δ8-THC and Δ9-Tetrahydrocannabinol (THC). International Journal of Innovation Scientific Research and Review. 2023; 5(4): 4315-4318.

[73] Malabadi RB, Kolkar KP, Chalannavar RK, Lavanya L, Abdi G. Hemp Helps Human Health: Role of phytocannabinoids. International Journal of Innovation Scientific Research and Review. 2023; 5 (4): 4340-4349.

[74] Malabadi RB, Kolkar KP, Chalannavar RK, Lavanya L, Abdi G. Cannabis sativa: Botany, cross pollination and plant breeding problems. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8 (4): 174-190.

[75] Malabadi RB, Kolkar KP, Chalannavar RK, Lavanya L, Abdi G, Baijnath H. Cannabis products contamination problem: A major quality issue. International Journal of Innovation Scientific Research and Review. 2023;5(4): 4402-4405.

[76] Malabadi RB, Kolkar KP, Chalannavar RK, Lavanya L, Abdi G. Medical Cannabis sativa (Marijuana or drug type): Psychoactive molecule, Δ9-Tetrahydrocannabinol (Δ9-THC). International Journal of Research and Innovations in Applied Science. 2023; 8(4): 236-249.

[77] Malabadi RB, Kolkar KP, Chalannavar RK, Mondal M, Lavanya L, Abdi G, Baijnath H. Cannabis sativa: Release of volatile organic compounds (VOCs) affecting air quality. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8(5): 23-35.

[78] **Malabadi RB**, Nethravathi TL, Kolkar KP, Chalannavar RK, Mudigoudra BS, Lavanya L, Abdi G, Baijnath H. Cannabis sativa: Applications of Artificial Intelligence and Plant Tissue Culture for Micropropagation. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8(6): 117-142.

[79] Malabadi RB, Nethravathi TL, Kolkar KP, Chalannavar RK, Mudigoudra BS, Abdi G, Baijnath H. Cannabis sativa: Applications of Artificial intelligence (AI) in Cannabis industries: In Vitro plant tissue culture. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8 (7): 21-40.

[80] Malabadi RB, Kolkar KP, Brindha C, Chalannavar RK, Abdi G, Baijnath H, Munhoz ANR, Mudigoudra BS. Cannabis sativa: Autoflowering and Hybrid Strains. International Journal of Innovation Scientific Research and Review. 2023; 5(7): 4874-4877.

[81] Malabadi RB, Kolkar KP, Chalannavar RK, Munhoz ANR, Abdi G, Baijnath H. Cannabis sativa: Dioecious into Monoecious Plants influencing Sex Determination. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8(7): 82-91.

[82] Malabadi RB, Kolkar KP, Chalannavar RK, Abdi G, Munhoz ANR, Baijnath H. Cannabis sativa: Dengue viral disease-Vector control measures. International Journal of Innovation Scientific Research and Review. 2023; 5(8): 5013-5016.

[83] Malabadi RB, Nethravathi TL, Kolkar KP, Chalannavar RK, Mudigoudra BS, Abdi G, Munhoz ANR, Baijnath H. Cannabis sativa: One Plant-One-Medicine for many diseases-Therapeutic Applications. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8(8): 132-174.

[84] Malabadi RB, Nethravathi TL, Kolkar KP, Chalannavar RK, Mudigoudra BS, Abdi G, Munhoz ANR, Baijnath H. Fungal infection diseases- Nightmare for Cannabis industries: Artificial intelligence applications. International Journal of Research and Innovations in Applied Science (IJRIAS). 2023; 8(8):111-131.

[85] Malabadi RB, Kolkar KP, Chalannavar RK, Baijnath H. Cannabis sativa: Difference between Medical Cannabis (marijuana or drug) and Industrial hemp. GSC Biological and Pharmaceutical Sciences. 2023; 377-381.

[86] Malabadi RB, Kolkar KP,Chalannavar RK, Acharya M, Mudigoudra BS. Cannabis sativa: 2023-Outbreak and Re-emergence of Nipah virus (NiV) in India: Role of Hemp oil. GSC Biological and Pharmaceutical Sciences. 2023; 25(01):063–077.

[87] Malabadi RB, Kolkar KP, Chalannavar RK, Acharya M, Mudigoudra BS. Industrial Cannabis sativa: Hemp-Biochar-Applications and Disadvantages. World Journal of Advanced Research and Reviews. 2023; 20(01): 371–383.

[88] **Malabadi RB**, Kolkar KP, Chalannavar RK, Vassanthini R, Mudigoudra BS. Industrial Cannabis sativa: Hemp plastic-Updates. World Journal of Advanced Research and Reviews. 2023; 20 (01): 715-725.

[89] Alcheikh A. Advantages and challenges of hemp biodiesel production: A comparison of hemp vs. other crops commonly used for biodiesel production. Masters Thesis submitted to the University of Gavle. 2015; 2-31.

[90] Ji A, Jia L, Kumar D, Yoo CG. Recent advancements in biological conversion of industrial hemp for biofuel and value-added products. Fermentation. 2021; 7: 6.

[91] Asokan MA, Prabu SS, Bollu A, Reddy MA, Ram A, Sukhadia DS. Emission and performance behaviour of hemp seed oil biodiesel/diesel blends in DI diesel engine. Materials Today: Proceedings. 2021; 46: 17: 8127-8132.

[92] Rheay HT, Omondi EC, Brewer CE. Potential of hemp (Cannabis sativa L.) for paired phytoremediation and bioenergy production. GCB Bioenergy. 2021;13:525–536.

[93] Brar KK, Raheja Y, Chadha BS, Magdouli S, Brar SK, Yang YH, Bhatia SK, Koubaa A. A paradigm shift towards production of sustainable bioenergy and advanced products from Cannabis/hemp biomass in Canada. Biomass Conversion and Biorefinery. 2022; https://doi.org/10.1007/s13399-022-02570-6.

[94] Li SY, Stuart JD, Li Y, Parnas RS. The feasibility of converting Cannabis sativa L. oil into biodiesel. Bioresource Technology. 2010; 101: 8457–8460.

[95] Parvez AM, Lewis JD, Afzal MT. Potential of industrial Hemp (Cannabis sativa 1 L.) for bioenergy production in Canada: Status, challenges and outlook. https://www.sciencedirect.com/science/article/pii/S1364032121000794.

[96] Chaowana P, Hnoocham W. et al., Utilization of hemp stalk as a potential resource for bioenergy. Materials Science for Energy Technologies. 2023; 7: 19–28..

[97] Khan IA, Prasad N, Pal A, Yadav AK. Efficient production of biodiesel from Cannabis sativa oil using intensified transesterification (hydrodynamic cavitation) method. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. 2019; 42(20): 2461–2470.

[98] Ahmad M, Ullah K, Khan MA, Zafar M, Tariq M, Ali S, Sultana S. Physicochemical analysis of hemp oil biodiesel: A promising non edible new source for bioenergy. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. 2011; 33(14): 1365–1374.

[99] Afif MK, Biradar CH. Production of biodiesel from Cannabis sativa (Hemp) seed oil and its performance and emission characteristics on DI engine fuelled with biodiesel blends. International Research Journal of Engineering and Technology. 20119; 6(8): 246–253.

[100] Mohammed MN, Atabani AE, Uguz G, Lay CH, Kumar G, Al-Samaraae RR. Characterization of hemp (Cannabis sativa L.) biodiesel blends with euro-diesel, butanol and diethyl ether using FT-IR, UV–Vis, TGA and DSC techniques. Waste and Biomass Valorization. 2020; 11(3): 1097–1113.

[101] Viswanathan MB, Cheng MS, Clemente TE, Dweikat I, Singh V. Economic perspective on coproducing ethanol and biodiesel from industrial hemp. Version https://www.sciencedirect.com/science/article/pii/S0959652621010945. 2020.

[102] Burton RA, Andres M, Cole M, Cowley JM, Augustin MA. Industrial hemp seed: from the field to value‑added food ingredients. Journal of Cannabis Research. 2022; 4:45.

[103] Zhao J, Xu Y, Wang W, Griffin J, Roozeboom K, Wang D. Bioconversion of industrial hemp biomass for bioethanol production: A review. 2020; University of Texas Rio Grande Valley. School of Earth, Environmental, and Marine Sciences.

[104] Prade T, Svensson S, Andersson A, Mattsson JE. Biomass and energy yield of industrial hemp grown for biogas and solid fuel. Biomass and Bioenergy. 2011; 35:3040-3049.

[105] Kuglarz M, Gunnarsson IB, Svensson S, Prade T, Johansson E, Angelidaki I. Ethanol production from industrial hemp: Effect of combined dilute acid/steam pre-treatment and economic aspects. Bioresour Technol. 2014; 163:236-243.

[106] Kuglarz M, Alvarado-Morales M, Karakashev D, Angelidaki I. Integrated production of cellulosic bioethanol and succinic acid from industrial hemp in a biorefinery concept. Bioresour Technol. 2016; 200:639-647.

[107] Das L, Liu E, Saeed A, Williams DW, Hu H, Li C, et al. Industrial hemp as a potential bioenergy crop in comparison with kenaf, switchgrass and biomass sorghum. Bioresour Technol. 2017; 244:641-649.

[108] Wawro A, Batog J, Gieparda W. Chemical and enzymatic treatment of hemp biomass for bioethanol production. Applied Sciences. 2019; 9:5348.

[109] Das L, Li W, Dodge LA, Stevens JC, Williams DW, Hu H, et al. Comparative evaluation of industrial hemp cultivars: Agronomical practices, feedstock characterization, and potential for biofuels and bioproducts. ACS Sustain Chem Eng. 2020; 8:6200-6210.

[110] Kreuger E, Sipos B, Zacchi G, Svensson S, Björnsson L. Bioconversion of industrial hemp to ethanol and methane: the benefits of steam pretreatment and co-production. Bioresour Technol. 2011; 102:3457-3465.

[111] Kitrytė V, Bagdonaitė D, Venskutonis PR. Biorefining of industrial hemp (Cannabis sativa L.) threshing residues into cannabinoid and antioxidant fractions by supercritical carbon dioxide, pressurized liquid and enzyme-assisted extractions. Food Chem. 2018; 267:420-429.

[112] Benelli G, Pavela R, Petrelli R, Cappellacci L, Santini G, Fiorini D, et al. The essential oil from industrial hemp (Cannabis sativa L.) by-products as an effective tool for insect pest management in organic crops. Ind Crop Prod. 2018; 122:308-315.

[113] Rehman MSU, Rashid N, Saif A, Mahmood T, Han J. Potential of bio-energy production from industrial hemp (Cannabis sativa): Pakistan perspective. Renewable and Sustainable Energy Reviews. 2013; 18:154-164.

[114] **Asokan MA**, Prabu SS, Kamesh S, Khan W. Performance, combustion and emission characteristics of diesel engine fuelled with papaya and watermelon seed oil bio-diesel/diesel blends. Energy. 2018; 145: 238-245.

[115] **Asokan MA**, Prabu SS, Prathiba S, Bade PKK, Nekkanti VM, Gutta SSG. Performance, combustion and emission characteristics of **Juliflora** biodiesel fuelled DI diesel engine. Energy. 2019; 19: 883-892.

[116] Haq A, Laiq Ur Rehman M, Rana QuA, Khan A, Sajjad W, Khan H, Khan S, Shah AA, Hasan F, Ahmed S, Islam A, Badshah M, Shah TA, Dawoud TM, Bourhia M. Production, optimization, and physicochemical characterization of biodiesel from seed oil of indigenously grown Jatropha curcas. Front. Energy Res. 2023; 11:1225988. doi: 10.3389/fenrg.2023.1225988.

[117] Gill P, Soni SK K, Kundu K. Comparative study of Hemp and Jatropha oil blends used as an alternative fuel in diesel engine. Agricultural Engineering International. 2011; 13: 3.

[118] Riayatsyah TMI, Sebayang AH, Silitonga AS, Padli Y, Fattah IMR, Kusumo F, Ong HC, Mahlia TMI. Current progress of Jatropha curcas commoditisation as biodiesel feedstock: A comprehensive review. Front. Energy Res. 2022; 9:815416.

[119] Bukhari SAZ, Ullah K, Ahmad M, Zafar M, Ullah A, Sultana S, Ibrahim MM, Hessien MM, Mersal GAM, Ghoneim SSM. Biodiesel from **Dodonaea plant Oil**: Synthesis and characterization—A Promising nonedible oil source for bioenergy industry. Front. Bioeng. Biotechnol. 2022; 10:864415.

[120] Ameen M, Zafar M, Nizami AS, Ahmad M, Munir M, Sultana S, Usma A, Rehan M. Biodiesel synthesis from Cucumis melo Var. agrestis seed oil: Toward non-food biomass biorefineries. Front. Energy Res. 2022; 10:830845.

[121] Alsaiari RA, Musa EM, Riz MA. Biodiesel production from **date seed oil** using hydroxyapatite-derived catalyst from waste camel bone. Heliyon. 2023; 9 e15606.

[122] Khan IU, Chen H, Yan Z, Chen J. Extraction and quality evaluation of biodiesel from six familiar non-edible plants seeds. Processes. 2021; 9: 840.

[123] Fadairo A, Ip WF. A Study on performance evaluation of biodiesel from **grape seed oil** and its blends for diesel vehicles. Vehicles. 2021; 3: 790–806.

[124] Aransiola EF, Ojumu TV, Oyekola OO, Ikhuomoregbe DIO. A study of biodiesel production from non-edible oil seeds: A comparative study. The Open Conference Proceedings Journal. 2012; 3: 18-22.

[125] Beyene D, Abdulkadir M, Befekadu A. Production of biodiesel from mixed Castor seed and microalgae oils: Optimization of the production and fuel quality assessment. Hindawi International Journal of Chemical Engineering. 2022; Article ID 1536160. 14 pages https://doi.org/10.1155/2022/1536160.

[126] Umaru M, Mohammed, Ibrahim MA, Sadiq MM, Aliyu AM, Suleiman B, Segun T. Production and characterization of biodiesel from **Nigerian mango seed oil**. Proceedings of the World Congress on Engineering. 2014; I: WCE 2014, July 2 - 4, 2014, London, U.K.

[127] Onoji SE, Iyuke SE, Igbafe AI, Nkazi DB. Rubber seed oil: A potential renewable source of biodiesel for sustainable development in sub-Saharan Africa. Energy Conversion and Management. 2016; 110: 125–134.

[128] Gohain PP, Sut D, Baruah SD, Kataki R. Biodiesel production from tea seed oil. AIP Conf. Proc. 1998; 020019. 2018; https://doi.org/10.1063/1.5049115.

[129] Bothon FTD, Montcho PS, Nonviho G, Dossa CPA, Tchiakpe L, Adomou AA, Avlessi FL. Physicochemical variability and biodiesel potential of seed oils of two Hibiscus sabdariffa L. Phenotypes. ACS Omega. 2020; 5:25561–25567.

[130] Ogunsuyi HO. Production of biodiesel using African pear (*Dacryodes edulis*) seed-oil as feedstock Acad. J. Biotechnol. 2015; 3(5): 085-092.

[131] Hasnain M, Munir N, Abideen Z, Macdonald H, Hamid M, Abbas Z, El-Keblawy A, Mancinelli R, Radicetti E. Prospects for biodiesel production from emerging algal resource: Process optimization and characterization of biodiesel properties. Agriculture. 2023; 13: 407. https://doi.org/10.3390/ agriculture13020407.

[132] Sajjad MOA, Sathish T, Rajasimman M, Praveenkumar TR. Experimental evaluation of Soapberry seed oil biodiesel performance in CRDI diesel engine. Scientifc Reports. 2023; 13:5699. https://doi.org/10.1038/s41598-023-32424-8.

[133] Stamenković OS, Gautam K, Singla-Pareek SL, Dhankher OP, Djalović IG, Kostić MD, Mitrović PM, Pareek A, Veljković VB. Biodiesel production from Camelina oil: Present status and future perspectives. Food and Energy Security. 2023; 12:e340. https://doi.org/10.1002/fes3.340.

[134] Asokan MA, Prabu SS, Prathiba S, Akhil VS, Abhishai LD, Surejlal ME. Emission and performance behaviour of flax seed oil biodiesel/diesel blends in DI diesel engine. Materials Today: Proceedings. 2021; 46: 17: 8148-8152.

[135] Musthafa B, Saravanan, B, Asokan MA, Devendiran S, Venkatesan K. Effect of ethanol, propanol and butanol on Karanja biodiesel with vegetable oil fuelled in a single cylinder diesel engine. Egyptian Journal of Petroleum. 2023; 32(2): 35–40.

[136] Musthafa B, Asokan MA. An experimental evaluation of cetane improving techniques for enhancing the performance and emission trade-off in diesel engine: A comparative study. Energy and Environment. 2023; https://doi.org/10.1177/0958305X231193866.

[137] Asokan MA, Prabu SS, Prathiba S, Jain V, Sarwate SM. Emission and performance behaviour of Orange peel oil/diesel blends in DI diesel engine. Materials Today: Proceedings. 2021; 46: 8114–8118.

[138] Asokan MA, Prabu SS, Prathiba S, Mittal H, Verma V. Emission and performance behaviour of Safflower oil biodiesel/diesel blends in DI diesel engine. Materials Today: Proceedings. 2021; 46: 8266–8270.

[139] Asokan MA, Prabu SS, Prathiba S, Bakshi R, Teja EV. Emission and performance behaviour of blends of diesel/lemongrass oil in DI diesel engine. Materials Today: Proceedings. 2021; 46: 8080–8085.

[140] Ahn E, Koncar M, Mittelbach M, Marr R. A low-waste process for the production of biodiesel. Separat. Sci. Technol. 1995; 30: 2021–2033.

[141] Iram S, Tariq I, Ahmad KS, Jaffri SB. Helianthus annuus based biodiesel production from seed oil garnered from a phytoremediated terrain, International Journal of Ambient Energy. 2022; 43:1: 1763-1771.

[142] Abdalla BK, Oshaik FOA. Base-transesterification process for biodiesel fuel production from spent frying oils. Agricultural Sciences. 2013; 4: 9B: 85- 88.

[143] ASTM. Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distilled Fuels Fuels'. ASTM. 2015.

[144] Mahajan A. Properties of biodiesel produced from various oilseeds. International Journal of Research in Environmental Science and Technology. 2011; 1: 4: 25-29.

[145] Adipah S. Biodiesel production from Allanblackia floribunda seed oil. Journal of Environmental Science and Public Health. 2019; doi: 10.26502/jesph.96120051.

[146] Ahtesham SA, Hebbal O. Pumpkin seed oil biodiesel, An alternate fuel to diesel- A review. International Research Journal of Engineering and Technology (IRJET). 2020; 07: 10: 700-707.

[147] Suryanto A, Sabara ZHW, Ismail H, Artiningsih A, Zainuddin U, Almukmin A, Nurichsan U, Niswah FW. Production of biodiesel from Kapok seed oil using ultrasonic. IOP Conf. Series: Earth and Environmental Science. 2018; 175: 012023. doi :10.1088/1755-1315/175/1/012023.

[148] Zhang S, Zhang L, Xu G, Li F, Li X. A review on biodiesel production from microalgae: Influencing parameters and recent advanced technologies. Front. Microbiol. 2022; 13:970028. doi: 10.3389/fmicb.2022.970028.

[149] Alhammad BA, Jamal A, Carlucci C, Saeed MF, Seleiman MF, Pompelli MF. Non-conventional oilseeds: Unlocking the global potential for sustainable biofuel production. Catalysts. 2023; 13: 1263. https://doi.org/10.3390/catal13091263.

[150] Purwanto P, Buchori L, Istadi I. Reaction rate law model and reaction mechanism covering effect of plasma role on the transesterification of triglyceride and methanol to biodiesel over a continuous flow hybrid catalytic-plasma reactor. Heliyon. 2020; 6 : e05164.

[151] **Malabadi RB,** Kolkar KP, Chalannavar RK. Industrial *Cannabis sativa*: Hemp oil for biodiesel production. Magna Scientia Advanced Research and Reviews. 2023; 09(02): 022–035.