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Jatropha: A Comprehensive Review of Its Potential as a Green Fuel

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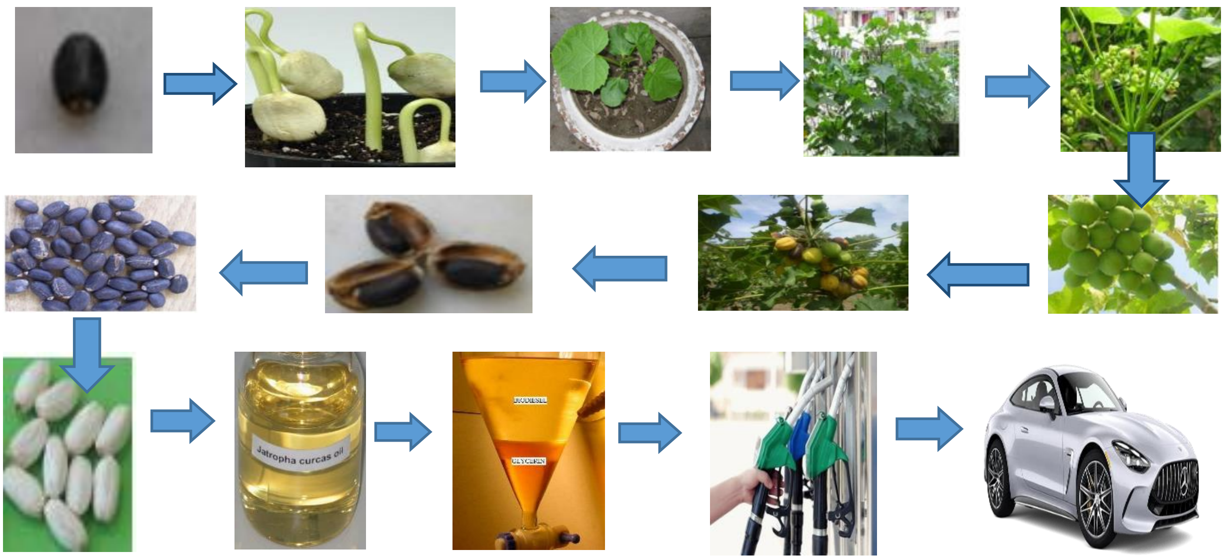
Abstract

The world's growing industrialization, population, and modernity caused a dramatic increase in petroleum demands for industry, transportation, heating and other uses. Depending on the continued exploitation, the planet's natural and mineral resources are being rapidly depleted, and the world's petroleum resources are predicted to run out entirely in 40 years. As a result, many researchers are searching for alternative fuel resources that may manufactured from renewable feedstock. Because of that biodiesel is becoming attractive due to its environmental benefits and come from renewable resources. *Jatropha* is a non-edible crop that is suitable for growing in tropical or subtropical regions. Jatropha could be the most suitable source for biodiesel production. Where it can grow on wide range of soils including sandy and gravelly soils, and marginal lands, saline soil, and requires very little water, not to mention fertilizer. Jatropha seed has high oil content, producing biodiesel similar to that of petroleum properties. Depending on that, the presented manuscript aimed to introduce Jatropha and review its potential as a green fuel, several approaches and techniques used to generate biodiesel from the oil of *Jatropha*.

Keywords: Jatropha, Biodiesel, Transesterification, Pyrolysis, and Cetane number.

Graphical abstract

Graphical abstract summaries the sequence of jatropha cultivation, oil extract process and generate biodiesel from the oil of Jatropha as follows:



Introduction

Jatropha curcas is a non-food bioenergy plant; nowadays it is used as an alternative substitute to fossil fuels [1]. Jatropha belongs to family *Euphorbiaceae*, which contains approximately 170 species of trees and shrubs. Jatropha has several names in based on local regions, such as goat nuts, barbados nuts, purging nuts, nettle spurge, or just Jatropha, but it is most commonly known as "Physic Nuts" [2].

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Jatropha is a small tree (shrub) oilseed can grow to height of 7-13 meters when it is fully grown (over 8 years old); moreover. According to the climate, Jatropha may be deciduous or evergreen. Jatropha is a monoecious plant that is usually pollinated by insects. Jatropha can grow in various conditions, it can grow up to 500 meters above sea level, and can withstand drought for a long time by losing its leaves, but it cannot survive in cold climates. Jatropha growth and productivity are affected by the availability of soil moisture and suitable temperature. Jatropha flowers twice a year; under Egyptian conditions, in April (the first one) and in December (the second one).

Along with biofuels, Jatropha is also helpful for reclaiming wasteland, controlling soil erosion, improving water infiltration, phytoremediation of various contaminated soils, protecting livestock, demarcating land, or erecting live fences around agricultural fields, as well as for soil carbon sequestration, fuel wood, green manure and sustainable environmental development [2-3].

Origin

Until now, the origin of Jatropha is still up for debate. However, Jatropha is native to Central America, and it is growing naturally in tropical regions of Africa. The Portuguese brought Jatropha to Asia and Africa as an oil-crop plant. Furthermore, it is found in wild, semi-wild and cultivated states in nearly every biogeographical zone, from the outer Himalayan ranges to coastal regions in India [3], as presented in Fig. (1).

Fig. 1. Cultivation limits of *Jatropha curcas* (source: [4-5]).

Scientific classification

Jatropha is one of *Euphorbiaceae* family, one of the largest Angiosperm groups with over 7,800 species spread across about 300 genera and 5 subfamilies globally [6]. Among the main genera belongs to this family, *Jatropha L*., belongs to sub-family *Crotonoideae*, and tribe Jatropheae, and it represented by about 200 species [1] additionally Jatropha plants scientific classification as follows:

1. **Kingdom:** Plantae.
2. **Subkingdom:** Angiosperms.
3. **Infrakingdom:** Streptophyta.
4. **Superdivision:** Embryophyta.
5. **Division:** Tracheophyta.
6. **Subdivision:** Spermatophytina.
7. **Class:** Magnoliopsida.
8. **Superorder:** Rosanae.
9. **Order:** Malpighiales.
10. **Family:** Euphorbiaceae.
11. **Subfamily:** Crotonoideae.
12. **Tribe:** Jatropheae.
13. **Genus:** Jatropha.
14. **Species:** *Jatropha curcas* Linn.

Botany

Jatropha curcas L. is commonly known as a shrub (small tree) with a smooth gray bark, which exudes a yellowish/milky color and an aromatic and astringent latex when cut.

• Roots

Normally, seedlings mostly form five roots, where one root is central and four roots are peripheral. However, in the vegetative propagation case, plants usually don't create a taproot.

• Leaves

Jatropha leaves vary in morphology from green to pale green color, alternate to sub-opposite, with three to five lobed with a spiral phyllotaxis; hypostomatic and stomata are of paracytic (Rubiaceous) type.

• Flowers

Jatropha curcas is a monoecious plant, the inflorescences are produced on terminals of branches, and it contains both female and male flowers, where the central female flower surrounds male flowers [2]. The flowers are usually unisexual, with only a few male flowers produced in each inflorescence. Both female and male flowers are open at the same time, therefore, the cross pollination could occur among flowers from the same plant or other plants. Female flowers and buds are somewhat larger than the male flowers [7].

• Fruits

During winter, when the shrub is leafless, Jatropha fruits are usually produced; the fruits are approximately 2.5 cm long. However, in optimum conditions, Jatropha may produce fruits several times during the year. Where each inflorescence yields approximately 10 or more ovoid fruits.

• Seed

During maturity stages, the Jatropha capsule changes in color from green to yellow to dark brown, as shown in Fig. (2). Where blackish, thin-shelled seeds are oblong and resemble small castor seeds. Averagely, seed weight per 1000 is about 727 g, and there are 1375 seeds/kg. Furthermore, fruit development process from flower stage to seed maturity may take from 80-100 days. Generally, the full production of Jatropha is usually achieved in the fourth or fifth season of cultivation [8].

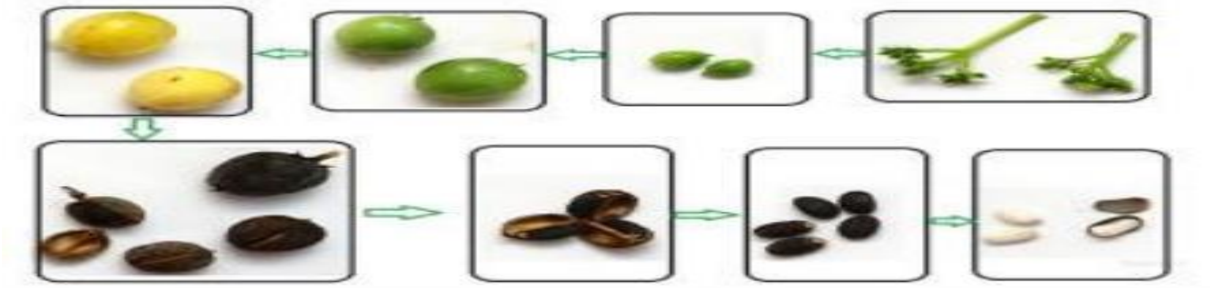

Fig. 2. Jatropha capsule changes in color during maturity (source: [9]).

Propagation

Jatropha can be cultivated by using two main methods: cutting and propagating seeds or seedlings. Techniques such as air layering, grafting, budding, and stem cuttings can all be used for vegetative growth. Additionally, to guarantee the maximum amount of rooting in stem cuttings it should be collected ideally from young plants after that treated with 200 micrograms per liter of IBA (rooting hormone). Jatropha is growing on nearly in all soil types, including sandy and gravelly soils, as well as saline soil, and it can even be found in wastelands. Jatropha roots have been shown to have mycorrhizae, which encourage growth, particularly in areas where phosphate is lacking. In just nine days, the seeds fully germinate. It is detrimental to apply manure during the germination process but beneficial once germination is accomplished [1].

Jatropha cultivation

Field cultivation involved digging 45 cm^3 pits in ground and transplanting with Jatropha seedlings at a density of 1330 to 1600 plants/ha (2.5 m intra-tree spacing and 2.5-3 m within rows). From March through October, Jatropha grew rapidly. Trees lost their leaves in the fall and went into hibernation until February [10].

Ecological requirements

Jatropha may grow anywhere between 30°N and 35°S, but it can also grow up to 500 meters above sea level. It requires temperatures between 20°C and 28°C with an annual rainfall rate ranging from 250 to 3,000 mm yr^{-1}. However, for its best production, 900-1200 mm of irrigation or rainfall per year is ideal [11]. Nevertheless, a very hot climate inhabits and flower fertilization and crop yield; also, Jatropha cannot tolerate cold weather. Aerated sandy loamy soil that is at least 45 cm deep is ideal for *Jatropha curcas* growth, while it may also be found in arid and semiarid areas. Jatropha might grow in alkaline soils, but only in soils with a pH between 6.0 and 8.5 [2]. Although Jatropha could tolerate heavy clay soil, it required adequate drainage because it could not withstand in the waterlogged condition. Also, it could grow and survive in marginal soils with water of poor quality, but this was reflected in its low productivity [10]. Along with the aforementioned, a crucial factor in improving Jatropha yield is the utilization of the proper fertilizers at the appropriate quantity and time application, where Jatropha fertilization begins at the second year following establishment. In order to optimize and more effectiveness, manure fertilizer should start with adding fertilizers to the planting pit at Jatropha cultivation, after that, the proper fertilizers were applied after seedling establishment. Jatropha considered as a drought-resistant plant, also withstand drought condition for a long time by dropping its leaves to reduce transpiration rate. On the other hand, the deficit of water quantity decreases the growth of tree and leaf development [12].

Uses

Jatropha is a versatile plant that has recently been grown all over the world and pushed as a biofuel plant to replace food oils in the production of biodiesel. Cosmetics, soaps, candles, adhesives, and dyes can all be made from Jatropha oil. In addition, the fruit's exocarp (coat), seed shell, and seed cake are great sources of potassium, phosphorus, and nitrogen and can be composted. Ash from roots and branches is used as lye in dyeing and as culinary salt [1]. Jatropha bark can be used to make a dark blue dye. Particularly on reclaimed ground, jatropha can be used to stop desertification and soil erosion. After all, because it contains harmful compounds, it can grow as living fractions, notably to exclude farm animals. Nevertheless, if the poisons are eliminated for animal feed, jatropha will offer a very affordable and nutrient-dense protein supplement [10].

Biodiesel

The depletion of natural energy sources such as petroleum reserves, rising costs, and environmental problems caused by fuel combustion like climate change and global warming prompted researchers to look for more economical, sustainable, renewable, and efficient energy sources. Biodiesel is a source of clean energy, where it safeguards the environment by reducing the amount of direct and indirect gases emissions, including CO_2, CO, SO_2, and HC. Where, biodiesel may reduce carbon monoxide (CO) emissions by 50%, and carbon dioxide (CO_2) emissions by 78% [13-14].

German engineer Rudolf Diesel (in 1893) realized that pure vegetable oils might be used as fuel for agricultural machinery and equipment. Rudolf demonstrated the first diesel engine running on peanut oil at the 1900 World's Fair in Paris.

Then, Brazilian scientist Expedito Parente (in 1977) created the first industrial method for producing biodiesel. The first plant biodiesel in Austria that used rapeseed as a feedstock was operational in 1989 [15]. Even though these experiments were successful, non-conventional fuels did not gain popularity until recently because petroleum products were so cheap [16].

Nowadays, along with the pollution problems, the growing human population is contributing to the quick depletion of Earth's natural resources, which is driving up energy consumption, which is predicted to reach 53% by 2030. Depending on that, biodiesel is becoming more popular as an alternative energy source. Where global biodiesel production nearly doubled to 43 billion liters in 2019, from an estimated 22 billion liters in 2010, according to data from the International Energy Agency (IEA). Fig. (3) shows specific information about biodiesel-producing countries. Currently, edible oils such as rapeseed (84%), sunflower oil (13%), palm oil (1%), soybean oil, and others (2%) are used to produce over 95% of the world's biodiesel globally.

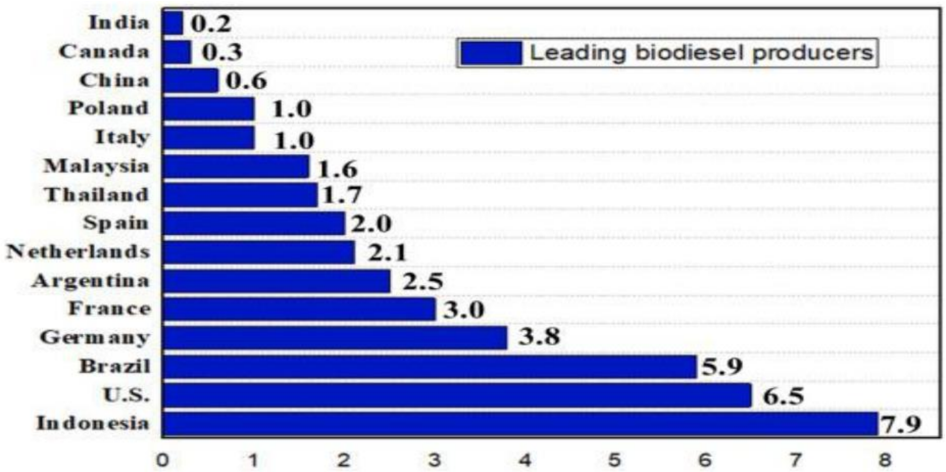

Fig. 3. Leading biodiesel-producing countries in 2019 (in billion liters) (source: [17]).

Four methods for producing biodiesel have been documented: pyrolysis (thermal cracking), micro-emulsion, transesterification, and direct use/blending of oils. Because of its greatest product yield and low pressure and temperature requirements, base-catalyzedalcoholysis (transesterification) is thought to be the most cost-effective method among them.

From an economic perspective, biodiesel manufacturing is shown to be dependent on the feedstock. Biodiesel is divided into four generations based on the feedstock's utilized in its production as well as various production methodologies. First-generation biodiesel is produced using edible feedstock's like rapeseed, palm oil, etc., where their use has given rise to many issues, including the conflict between food and fuel as well as environmental issues, including deforestation and the severe depletion of essential soil resources. Each of these issues adversely influenced the economic feasibility of producing biodiesel from edible oil. As a result, the second-generation biodiesel focuses on investigating novel, inexpensive, non-edible crops for agriculture, and using by-products in the manufacturing of biodiesel might drastically lower its price (Fig. 4). Such as waste oil and rubber seed, neem, Jatropha, etc. Moreover, the third generation of biodiesel uses microalgae, which are feedstock that does not compete with crops for land. While the fourth generation, which includes genetically modified algae, electro-fuels, and photobiological solar fuels, is categorized as a new field of research that requires further investigation and intensive studies in the future [18]. Furthermore, the primary biofuel components of diverse agricultural biomasses produced via various biochemical pathways are biodiesel-originated biofuels, such as bioethanol, biodiesel and biogas [19]. Now, the United States, which is quickly emerging as the primary producer of biodiesel, uses soybeans, whereas Europe uses rapeseed [20].

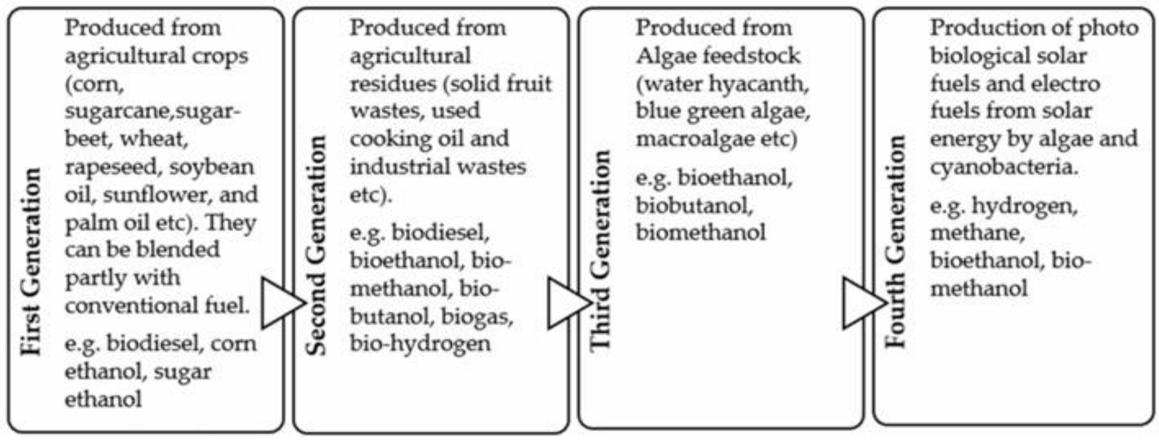

Fig. 4. Classification of biofuels (source: [21-22]).

In developing nations, non-edible crops are typically utilized as biodiesel sources to lower the cost of producing biodiesel, as the feedstock alone accounts for 75% of the entire expenses as presented in Fig. (5). Jatropha is potential plant for biodiesel production due to its ability to grow anywhere, its low water and fertilization requirements, and its ability to be grown on marginal soils. It also produces a large number of seeds that contain between 30 and 35% non-edible oil, and the Jatropha plant produces between 400 and 2,200 liters of oil per hectare. Jatropha oil consists of up 75% unsaturated fatty acids, about 76-78% of oleic and linoleic acids, the major constituents of Jatropha oil were oleic acid ranging from 12.8 to 48%, palmitic acid 0.14-20%, stearic acid 1.48-17%, and linoleic acid, which made up 28.7-46.7% of the oil. Minor constituents such as erucic acid, myristic acid, palmitoleic acid, arachidic acid, and linolenic acid were also found [23].

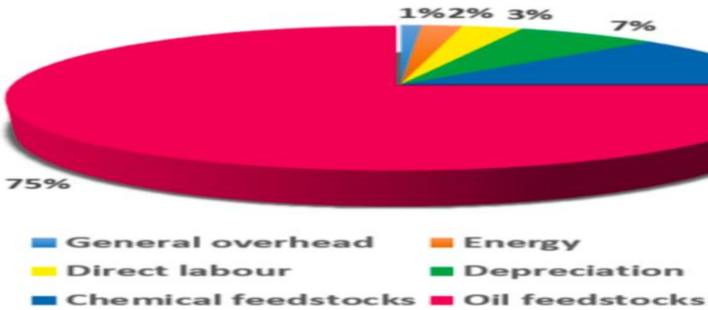

Fig. 5. General cost breakdown in biodiesel production (source: [23]).

Oil extraction methods

Oil extraction techniques are essential in biodiesel production. Due to its high yield and quality, solvent extraction is the most widely used method for oil extraction. It effectively uses polar solvents to extract oils, and it is now used in industry. The solvent extraction process can recover 90-98% of the available oil [24]. Comparing this process to mechanical and conventional extraction methods, it produces larger amounts of oil with lower water content. While the engine-driven screw press method can recover 75-80% of the available oil, the manual ram press technique can recover 60-65% [25]. However, these methods yielded lower oil recovery rates, with the resulting oil containing impurities such as water, metals, and dust, all of which compromised the quality of biodiesel production. Furthermore, the supercritical CO_2 extraction method, where CO_2 acts as a solvent to remove oils from seeds, eliminates the need for degumming and dehydration processes. This method reduces time and energy requirements compared to traditional solvent extraction. It is also environmentally friendly due to minimal solvent usage and oil purification.

Because of their high viscosity, acid contamination, gum production, and increased lubricating oil thickness, Jatropha oil is not used directly as fuel in compression engines. Therefore, vegetable oils are treated to acquire characteristics similar to fossil fuels, especially viscosity and volatility characteristics. Moreover, it has been discovered that blending Jatropha bio-diesel with petro-diesel lowers the biodiesel's viscosity to the permittivity limitations. Whereas, in compression ignition (CI) engines, a blend of 20% vegetable oil and 80% diesel fuel can be utilized directly [26-28]. As the blend ratio of biodiesel increases, it is anticipated that the oxygen content of the fuel blends will rise, and the improved combustion quality brought about by the higher oxygen content will result in a decrease in emission gas [29].

Factors affect biodiesel production

The physicochemical qualities of biodiesel are greatly impacted by several factors, including variations in feedstock's and inherent characteristics, handling, manufacturing procedures, and storage conditions. Below is a discussion of the primary physicochemical characteristics of biofuels made from different feedstock's [30-31].

Cetane number

A crucial measure of fuel quality, especially for diesel engines, is the cetane number. According to [32], a high cetane number often denotes a quick self-ignition capacity, improved combustion efficiency, and a shorter ignition delay time, or the amount of time between fuel injection and the combustion chamber's commencement of ignition. Furthermore, it was shown that Jatropha biodiesel had a cetane number between 48 and 59, while diesel have cetane number ranging between 47 and 50, which was marginally lower than of biodiesel [33].

Viscosity

Viscosity is a measure of fuel flow capacity. In the combustion chamber, a lower viscosity makes fuel delivery easier, while a higher viscosity decreases thermal efficiency [34]. Because of high kinematic viscosity, biodiesel's low fuel fluidity occurs, which harms fuel atomization and can lead to issues with the fuel injector and engine operation, including incomplete combustion, carbon deposition, and smoke. Several methods may follow to resolve the high viscosity such as heating or pyrolysis, blending, and chemical treatment [29]. According to [33], the viscosity of Jatropha oil was between 34 and 50 CST, whereas the viscosity of Jatropha biodiesel was between 4.3 and 5.7 CST.

Acid number

In the fuel sample, the acid number indicates the amount of free fatty acids. According to [35], an increased acid number results in corrosion issues in the engine's fuel delivery system. Additionally, the acid numbers of Jatropha oil and biofuel are 28.0 mg $KOHg^{-1}$ and 0.40 mg $KOHg^{-1}$, respectively.

Cloud point

Cloud point is the lowest temperature at which the fuel's wax crystallizes and gives the fuel a hazy look. The amount and type of saturated fatty compounds affect cloud point, while mustard oil produces the highest CP value at 16°C [36].

Oxidative stability

Oxidative stability is the fuel resistance against oxidation, and it is an essential factor that significantly effects fuels storage duration and condition [37]. Biodiesel containing higher oxygen content is highly susceptible to oxidation deterioration. The degree of oxidation among biodiesels fluctuates according to their fatty acid composition [38].

Flashpoint

Flashpoint is the minimum temperature at which the fuel vapors catch fire when they are exposed to any ignition source. The flashpoint of biodiesel fuels is more than 150°C, whereas common diesel has a flashpoint value of 55-65°C [39]. Flashpoint of Jatropha oil is very high (above 200˚C), then by converting the Jatropha oil to biodiesel, the flashpoint has reduced to 163˚C (approximately 26% reduction) [33].

Calorific value

Calorific value (CV) indicates the amount of energy released from a unit quantity of the fuel is burned. A fuel with a greater CV value is more beneficial for an internal combustion engine [31]. Calorific value of Jatropha biodiesel is ranging between 37:40 MJ/kg, which lower than diesel fuel (42-45 MJ/kg). This is indicating that biodiesel is 11.5% approximately lower in calorific value compared to diesel fuel [33].

Iodine number

Iodine number (IN) is indicating to the quantity of iodine absorbed by double bonds of the FAME molecules in 100 g of the fuel sample. Linseed oil has the maxim IN value (156.7), whereas coconut oil has a minimum IN value of approxmetly10 [39].

Biodiesel methods

Long chain fatty acid monoalkyl esters produced from vegetable oils or animal fats are called biodiesel. Biodiesel can be manufactured in four ways: transesterification, microemulsions, direct usage, and blending, as well as thermal cracking, also known as pyrolysis. A detailed discussion of each technology is presented in this section.

1. Transesterification

Due to its simplicity and the high quality of fuel, it generates transesterification, the reaction of alcohol and oil to produce ester and glycerol in the presence of an acid or basic catalyst is the most successful of these techniques. It has been used commercially in both industrialized and developing countries, including Canada, Italy, New Zealand, Germany, France, and Brazil. Because of its physical characteristics and reduced cost, methanol is utilized in this process to produce biodiesel. Due to methanol's low boiling point (65°C), the industry often establishes a maximum reaction temperature of 60°C, particularly when methanol is utilized [40].

Transesterification processes are classified into two types: catalytic and non-catalytic. Where in the catalytic process a catalyst is required to start the reaction; sodium hydroxide, potassium hydroxide, and sodium methoxide are examples of several kinds of homogeneous catalysts that can be used during the process. Numerous factors influence the transesterification process, and these parameters change depending on the reaction conditions. If the parameters are not optimized, the reaction will either be incomplete or yield much less. To produce high-quality biodiesel that meets guiding standards, each feature is essential. The most important elements influencing the transesterification process are as follows: (a) the value of water, moisture and free fatty acids, (b) the type of alcohol and the molar ratio that was used, (c) the concentration and type of catalyst, (d) the temperature and time of the reaction, (e) the mode and rate of stirring, (f) the purification of the final product, (g) the intensity of mixing, (h) the impact of using organic co-solvents; and (i) specific gravity [17]. The primary result of transesterification is methyl ester, while glycerol is a byproduct. The general equation, where R1, R2, and R3 are fatty acid chains, depicts the reaction of triglycerides with alcohol as shown in Fig. (6). The five primary chain types found in biological sources are oleic, linoleic, stearic, palmitic, and linolenic [41-42].

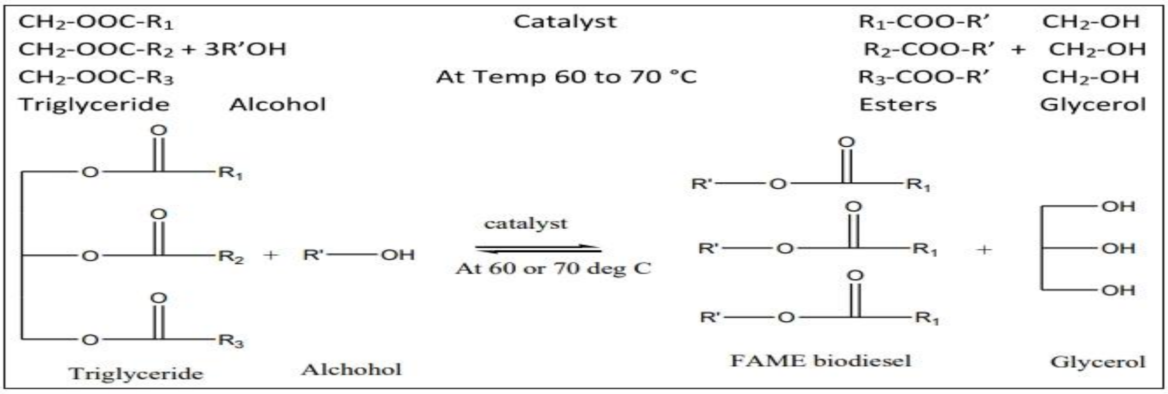

Fig. 6. Transesterification process (source: [44]).

Because of Jatropha, oil's high FFA content (18.25 weight percent) may also cause saponification during transesterification, which is why the traditional method of producing biodiesel from it involves an esterification treatment before the transesterification. Oils should contain no more than 1% FFA during transesterification, which come after esterification process. This treatment is a reversible reaction in which acid catalysis transforms free fatty acids (FFA) into alkyl esters. Acid catalyzes the reactions of alcohol and FFA to produce water and alkyl ester. The well-known equation that represents the simplified form of this chemical reaction. R1-COOH (FFA) + R2-OH (Alcohol) = R1-COO-R2 + H_2O [43].

According to [41], biodiesel was created by esterification utilizing sulfuric acid as an acid catalyst before transesterification and maintained at a level of less than 1.0 mg-KOH/g-oil under specific conditions. FFA conversion in esterification exceeded 97%. The yield of methyl ester during transesterification exceeded 98%. Reusable solid acid catalysts such as nanoporoustitanosilicates, SiO_2·HF, and ZnO/SiO_2 are being investigated for plant-based oil conversion, and a variety of substances, including mineral acid, can be employed to lower the quantity of free fatty acids [3].

The catalyst used for the transesterification process

Alkaline solid catalyst

Alkali-catalyzed transesterification using CaO/MgO was doped with strontium (Sr). Adding Sr enhanced the catalyst activity with high stability for several cycles. Biodiesel from Jatropha was 96% after 3h of reaction time [45]. Also, this catalyst exhibits good reusability, as the biodiesel yield remained 86% after fourth time utilization. Lately, waste orange peel was calcinated at 600°C for 120 minutes, and these were used as the heterogeneous catalyst for the transesterification process of waste orange peel oil. Usually, alkali catalyzed transesterification is faster than acid catalyzed transesterification [46].

Acid catalyst

HCl and sulfuric acid (H_2SO_4) are the most well-known acid catalysts. Compared to alkaline catalysts, acid catalysts have less activity and yield lower levels, but they are nevertheless utilized when the amount of free fatty acid exceeds 1% [47]. Acid catalysts, on the other hand, are not a good method since they are more corrosive than liquid-based catalysts. Alcohol purity is also important because high concentrations of alcohol are needed for rapid conversion in acid-catalyzed transesterification processes. Additionally, compared to base-catalyzed transesterification, acid-catalyzed transesterification of vegetable oils typically requires very large alcohol-to-oil molar ratios to obtain a certain yield. Additionally, high reaction temperatures are necessary for acid-catalyzed transesterification reactions to increase the alcoholic polar medium's miscibility into a non-polar oily phase and achieve a rapid reaction rate. Moreover, the creation of acidic effluent and the catalyst's non-reusability cause serious separation issues in acid-catalyzed transesterification, and the necessary equipment is expensive [48].

Magnetic catalyst

A mixture of Ca-Fe composites and a magnetic-based catalyst demonstrated encouraging activity in the generation of biodiesel. Even after the ninth cycle, the magnetic structure of $CaSO_4/Fe_2O_3$-SiO_2 shows an 86% biodiesel production with immediate catalyst recovery. The combination of this catalyst's small sizes, large in surface area and high order of porous structure accounts for its high activity [49-50].

Enzyme catalyst

Rhizopus oryzae and *Carica papaya* are two lipases that were investigated in order to create biodiesel based on Jatropha. They demonstrated how these biocatalysts inhibited the production of glycerol. Only between 51 and 65% of the biodiesel was produced at the 4-hour reaction time [51]. The expensive cost of enzymes prevented their widespread use in industry. Fig. (7) shows the specifics catalysts classification

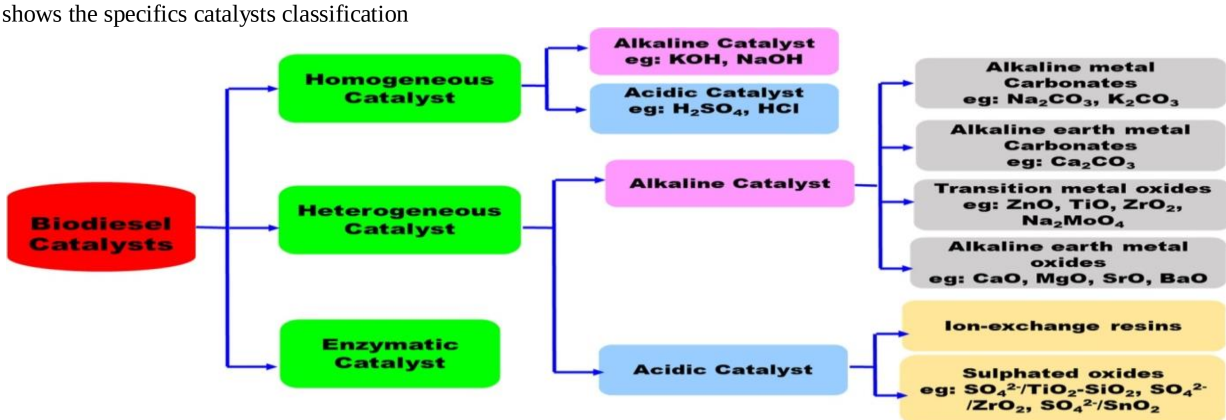

Fig. 7. Categorization of the catalysts utilized in biodiesel production (source: [17]).

2. Micro-emulsion

Micro-emulsion is a promising alternative to conventional diesel fuel due to its ability to reduce viscosity. It is an isotropic liquid containing oil, water, and surfactants, with alcohol being a common surfactant. Micro-emulsion biodiesel is simple, high yielding, and has low energy consumption, making it a promising alternative to direct-use methods. It can lead to more complete combustion, reducing emissions and contributing to environmental sustainability [52]. However, it also faces potential issues like carbon deposit formation, incomplete combustion, and injector needle sticking. Additionally, it may cause premature injection nozzle deterioration, deposits on fuel injection pump components, and incomplete combustion during engine start. Over time, biodiesel microemulsions may face stability issues, affecting long-term storage and usability.

Compatibility with different engine types and fuel systems may also vary, causing modifications or adaptations on the engines [40].

3. Direct use and blending

Diesel engines have been powered directly by feedstock, particularly vegetable oils, since the turn of the 20th century. Compared to conventional diesel, direct use of biodiesel usually results in fewer pollutant emissions like hydrocarbons (HC), particulate matter (PM), sulfur dioxide (SO_2), carbon dioxide (CO_2), and carbon monoxide (CO). The biodiesel component of the fuel mix can be freely adjusted through blending; popular mixes include B5 (5% biodiesel, 95% diesel) and B20 (20% biodiesel, 80% diesel). Furthermore, blending reduces the need for quick engine adjustments by providing a gradual switch from regular diesel to biodiesel. Additionally, mixing biodiesel with diesel fuel might increase combustion efficiency, which may lead to better fuel quality and fewer engine deposits [53]. Previous studies showed that diesel engines fueled with pure palm oil had higher specific fuel consumption and ignition delay compared to diesel fuel. However, this method led to higher emissions of HC, CO, and CO_2 and was considered impractical due to engine modifications. Biodiesel also had poorer cold weather performance compared to conventional diesel. Blending vegetable oils with diesel fuel has been suggested as an alternative, with studies showing lower emissions of CO and NO_x [54]. However, there are limitations on the maximum blend ratio of biodiesel with conventional diesel fuel, such as engine compatibility and storage stability. The cost-effectiveness of biodiesel blends depends on factors like feedstock availability, production costs, and market fluctuations in fossil fuel prices [40].

4. Thermal cracking

Thermal cracking, also known as pyrolysis, is a process that breaks down oil molecules into hydrocarbons, similar to fossil fuels. It produces gas, organic products, water, and coke, which can be oxygen-containing compounds or hydrocarbon compounds. It can also be used to produce biodiesel, which can be produced under atmospheric pressure and mild temperature conditions. The main reaction is the breakdown of aliphatic carbon bonds, which produce fuel with a high-octane number. Thermal cracking involves slow heating until 420°C, while catalytic cracking starts at 350°C as presented in Fig. (8). [55]. Catalytic cracking is more cost-effective due to lower energy consumption and lower temperature and is environmentally friendly, generating minimal waste and meeting environmental regulations [56]. However, some researchers argue that biodiesel produced through thermal cracking may have lower viscosity, cetane number, flash point, and pour point compared to other petroleum diesel fuels. This could lead to poor lubrication, increased engine wear, and difficulties in maintaining proper lubrication conditions. Additionally, the biodiesel produced through thermal cracking may be unstable and incomplete, potentially causing combustion issues and incomplete burning in the engine. The process may also require high-energy input, affecting the overall environmental footprint and economic viability [40].

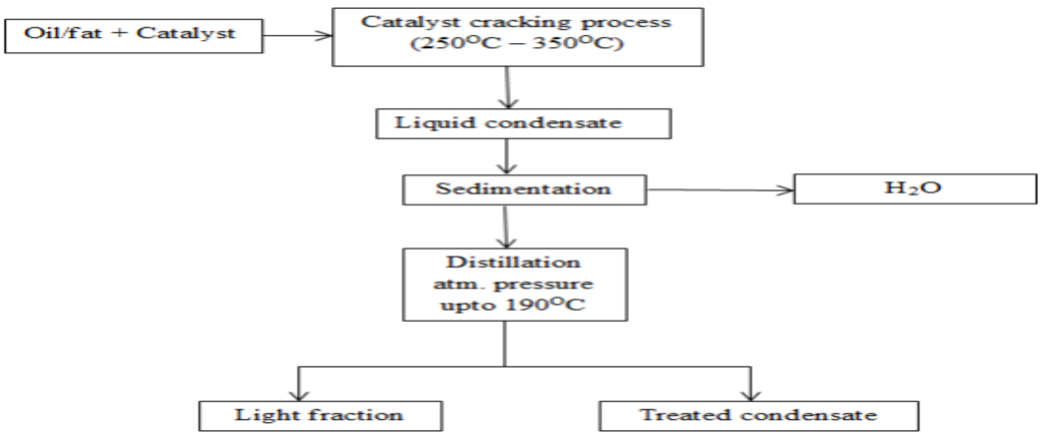

Fig. 8. Thermal cracking process (source: [56]).

Economic Feasibility

The annual production of Jatropha seeds varies from 0.1 tons per hectare (t/ha) to more than 14 tons/ha. These seeds contain about 30-35% of non-edible oil. Depending on density, 158-396 gallons of oil can be produced from one hectare of land. The efficiency of biodiesel production from Jatropha oil was 91.64%. The magnetic stirrer used 875 W.h. per kg of oil, whereas the boiler used to wash the biodiesel used 1177.5 W.h. per kg. An energy consumption of 2052.5 W.h per kilogram of Jatropha oil was required to create biodiesel [57]. So, 980 g of pure biodiesel may be made from 1,000 g of Jatropha oil, which emits around 80% less CO_2 and 100% less SO_2 than conventional diesel [58].

Engine Performance and Emission of Using Jatropha Based Biodiesel

According to [59], biodiesel fuels burn more effectively because they contain more oxygen. Engine torque, brake power (BP), brake-specific fuel consumption (BSFC), brake-specific energy consumption (BSEC), brake thermal efficiency (BTE), exhaust gas temperature (EGT), and brake-specific fuel consumption (BSFC) are often the metrics that researchers look at when assessing engine performance [60]. To probe the emissions, the authors often look at 1) hydrocarbon emissions (HC), 2) nitrogen oxides (NO_x), 3) carbon dioxide (CO_2), 4) carbon monoxide (CO), and 5) smoke opacity (SO). Blended biodiesel can sometimes perform better in terms of BP than conventional diesel fuel [37]. According to several studies, employing Jatropha biodiesel lowers BTE [61]. BP decreases as the percentage of biodiesel in the fuel blend rises [62], while BTE decreases as the percentage of Jatropha biodiesel in the fuel mix increases [63]. Increasing the percentage of Jatropha biodiesel in the diesel-biodiesel blend lowers HC emissions [64]. Compared to diesel fuel, an increase in the percentage of biodiesel results in a reduction in HC emissions of 14.91-27.53 percent. Generally, lower HC emissions are seen at full load conditions compared to other load conditions [65]. In most cases, the NO_x emissions from Jatropha biodiesel are higher than those from diesel fuel [67]. At full load, Jatropha biodiesel and its blends typically have 10–40% lower CO emissions than diesel [68-69]. The higher the load percentage, the greater the CO emissions. In the case of Jatropha biodiesel and its blends, smoke opacity decreases with increasing blend biodiesel percentage but increases with increasing load [63] [69].

Jatropha situation in Egypt

Egypt must contend with the issues of population increase, energy consumption, and energy generation to achieve its contemporary development objectives. In 2013, Egypt accounted for over 20% of Africa's total oil consumption and over 40% of its total dry natural gas consumption, making it the continent's largest consumer of both natural gas and oil. A significant budget deficit and an increase in energy demand have been caused by energy subsidies, which cost the government $26 billion in 2012 [70].

In 1986, Egypt's New & Renewable Energy Authority (NREA) was created to serve as the country's main hub for growing initiatives to create and market renewable energy technologies. However, the trial with Jatropha growing started in 1997 on a modest scale in Egypt using *Jatropha curcas* seed supplied from India. "The National Program for Safe Use of Treated Sewage Water for Afforestation," which aims to increase the amount of green space in the desert by introducing forest plantations (man-made forests) and producing high-value trees using treated sewage water (drip irrigation), where 42 hectares of Jatropha were established in 2001 using treated sewage water (drip irrigation) [7].

The encouraging outcomes of Jatropha prompted the Egyptian authorities to more extensively plant this species. Jatropha plantations are believed to be viable in all desert areas, like the New Valley and the governorates of Upper Egypt. It is also possible to plant Jatropha on marginal terrain. As a result, it is worthwhile to research the concept of expanding the Jatropha plantings to all suitable land regions. Currently, Jatropha occupies around 844 hectares in Egypt as depicted in Fig. (9) according to [71].

Even though there are Jatropha plantations in Egypt, the primary objectives of planting them are reforestation, desertification prevention, sewage water use, reducing global warming, and combating climate change. Additionally, scientific research and experiments on the plants' potential in various fields are being conducted.

Indeed, in spite of the fact that countless studies have focused on the conventional importance of Jatropha plants, little are practical applied on how biodiesel can be manufactured. However, in Egypt, the biofuel industry only consists of scientific experiments on biofuel production techniques and engine modifications to consume biofuels; there is no actual production. Therefore, further practical studies on biodiesel production from Jatropha are highly needed in Egypt.

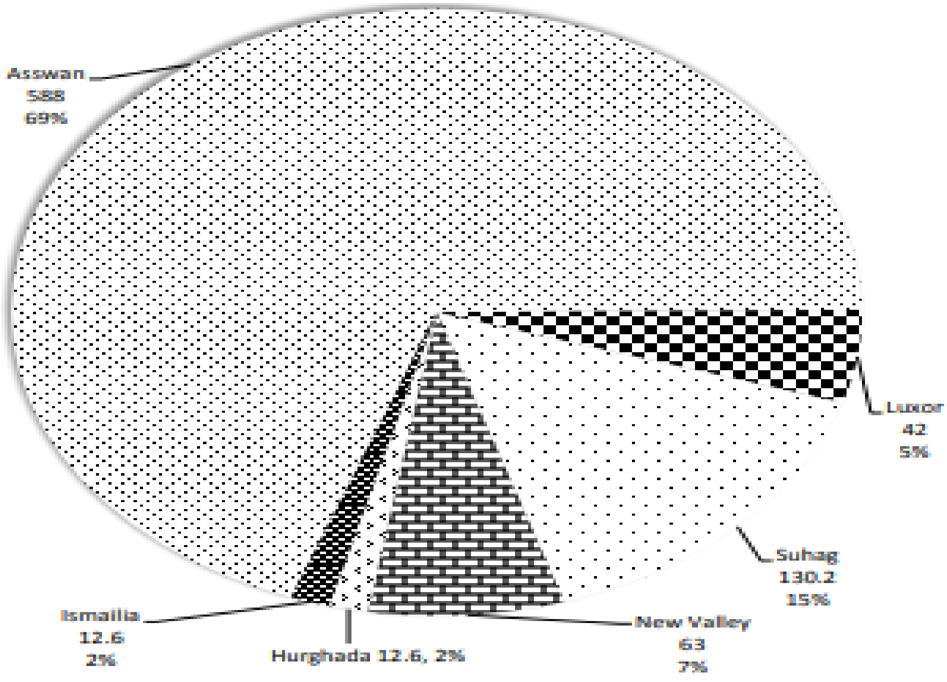

Fig. 9. Land area cultivated by Jatropha (source: [7]).

Conclusion

Climate change, pollution, and resource constraints are the three main issues that arise as the world strives for both sustainable and environmentally friendly agricultural production on the one hand and adequate production on the other, which can support food security and energy resources for the expanding global population. Jatropha may therefore be the best option in this situation due to its high yield potential, ability to thrive under stressful conditions, resistance to drought, and its use in arid regions to reduce soil erosion and prevent desertification. Except for areas that are flooded, Jatropha can grow practically anywhere, including on saline, sandy, and gravelly soils. Recently, the main source for producing biodiesel has shifted from edible crops to Jatropha oil due to its potential benefits for environment, such as desertification combating and fewer impacts compared to fossil diesel, which makes Jatropha not only an energy crop, but more and more. In expansion to the above, we require more rigorous research on oil extract and biodiesel manufactory from Jatropha oil, particularly emphasizing the need for further studies on biodiesel as a good and save alternative to petroleum diesel fuels.

Conflicts of interest: Authors declare no conflict of interest.

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