Chapter 12

Jatropha Biofuel Industry: The Challenges

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http://dx.doi.org/10.5772/64979

Abstract

Considering environmental issues and to reduce dependency on fossil fuel many countries have politicized to replenish fossil fuel demand from renewable sources. Citing the potential of Jatropha mostly without any scientific and technological backup, it is believed to be one of the most suitable biofuel candidates. Huge grants were released by many projects for huge plantation of Jatropha (millions of hectares). Unfortunately, there has been no significant progress, and Jatropha did not contribute much in the energy scenario. Unavailability of high-yielding cultivar, large-scale plantation without the evaluation of the planting materials, knowledge gap and basic research gap seem to be the main reasons for failure. Thus, the production of Jatropha as a biofuel has been confronted with various challenges such as production, oil extraction, conversion and also its use as a sustainable biofuel. In this chapter, we disclose the challenges and possible remedy for the contribution in the biofuel industry.

Keywords: *Jatropha curcas*, biofuel industry, renewable energy, challenges, solutions

1. Introduction

Jatropha belongs to the family Euphorbiaceae and has 175 species. It has originated from tropical America and has spread all over the tropics and subtropics of Asia and Africa [1]. Throughout the world, more than 1,000,000 ha of Jatropha have been propagated. Majority (85%) of them are in the Asian countries, i.e., India, China and Myanmar; the remaining, 12% in Africa and 2% in Latin America (Brazil and Mexico). India is the largest cultivator of

Jatropha [2]. In the ancient times, Jatropha has been used in various fields, such as storm protection, soil erosion control, firewood, hedges and traditional medicines [3–6]. The seed oil of Jatropha is also used as lamp fuel, soap manufacturing ingredient, paints and as a lubricant [4, 7, 8]. The characteristics of Jatropha seed oil match with characteristics of diesel [9–11], thus it is called a biodiesel plant [12]. Jatropha grows on diverse wasteland without any agricultural impute (irrigation and fertilization) and has 40–60% oil content [12, 13]. Easy propagation, rapid growth, drought tolerance, pest resistance, higher oil content than other oil crops, adaptation to a wide range of environmental conditions, small gestation period, and optimum plant size and architecture (which make the seed collection more convenient; actually inconvenient [14]) are some characteristics of Jatropha [15], which makes it a promising crop for biofuel [16]. Although Jatropha ranked behind palm (palm > *Calophylum inophyllum*> Cocus sp. > Jatropha) according to annual oil yield/hectare, it is favoured as a non-edible feed stock [17, 18]. A number of earlier reports, proceedings, expectations and assumptions predicted that the seed yield of Jatropha range from 2 to 5 Mg/ha and even 7.8 to 12 Mg/ha^{-} without any scientific and technological backup [19].

There is a complete mismatch between theoretical expectation and actual seed production of Jatropha in field conditions [9, 20–22]. The research on Jatropha opened the floodgate to the scientific community to grab funds and publish papers in high impact journals because seed oil of Jatropha has characteristics of biodiesel and this crop was non-native of arid, semiarid and subtropical regions. Singh and co-authors [19] depict the expectation and contribution picture from Jatropha policy (**Figure 1**). The reported yields of Jatropha in field conditions in India, Belgium, South Africa and Tanzania, are 0.5–1.4 mg/ha/yr, 0.5 mg/ha/yr, 0.35 mg/ha/yr and 2 mg/ha/yr, respectively [23]. The less productivity is because of unavailability of suitable high yielding varieties, large-scale plantation without evaluating the genetic potential of planted materials, consideration of Jatropha as no/low impute crop and lack of knowledge on agronomy. In this chapter, we present the challenges confronted by Jatropha as a biofuel and recommended solutions.

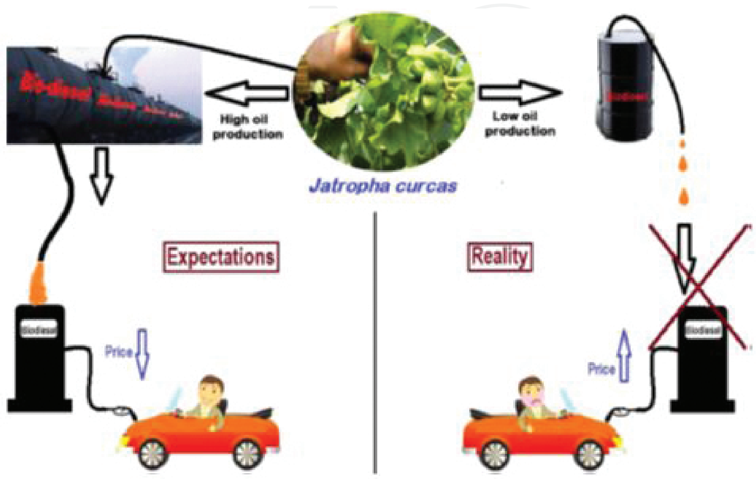

Figure 1. Expectation and contribution from Jatropha biofuel industry.

http://dx.doi.org/10.5772/64979

2. Potentials of Jatropha

Jatropha has multiple uses (**Figure 2**). Jatropha seed oil possesses biodiesel and jet fuel production potentials. Its wood, leaves and fruits have been using as firewood in rural areas. It also has industrial applications. Preparation of soap and cosmetics, and dyeing clothes and fishing nets are some of its common applications. Traditionally, Jatropha has been known as a medicinal plant. The therapeutic compounds from Jatropha can be used as anti-microbial, anti-inflammatory, healing, homeostatic, anti-cholinesterase, anti-diarrheal, anti-hypertensive and anti-cancer agents in modern pharmaceutical industry. As it contains toxins, before using Jatropha and/or its derivatives as a therapeutic agent, toxicological studies must be conducted. Jatropha seed cake can supplement animal feed and organic fertilisers as it bears higher percentage of protein and other nutrients. Soil erosion control and used as hedges are prehistoric uses of Jatropha.

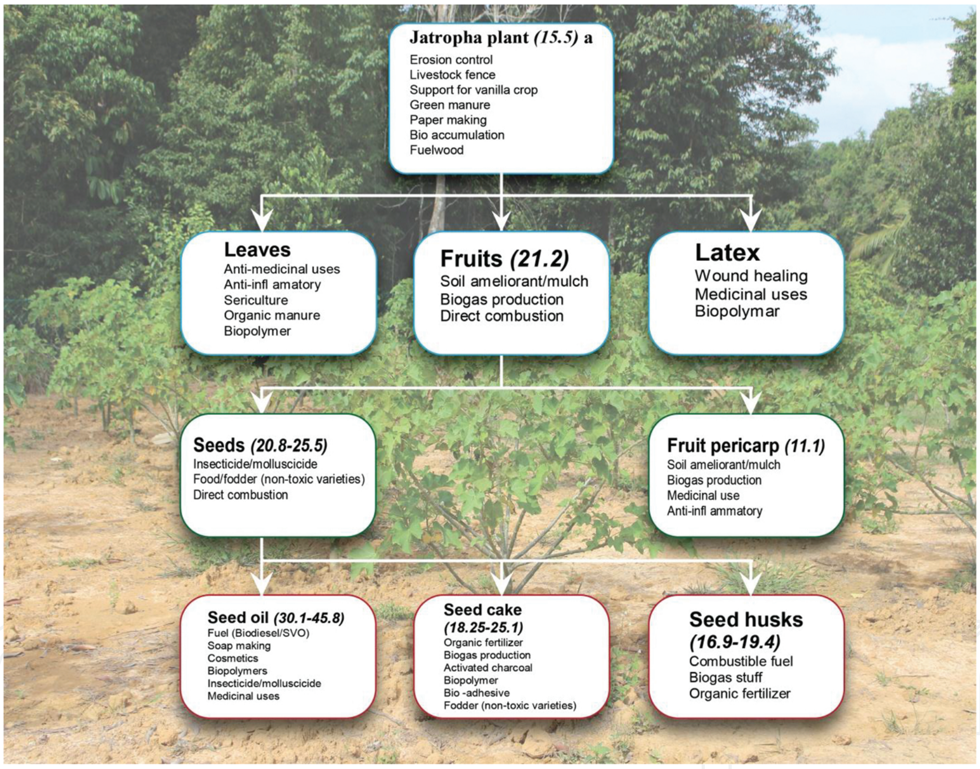

Figure 2. Multipurpose uses of *Jatropha curcas*.

2.1. Jatropha as energy source

Various features like, ease of production, sustainability and environmentally friendly nature of biomass draw attention as a potential renewable energy to replenish fossil fuel demand. Among the crops identified as energy crops for first generation biofuels, *Jatropha curcas* L. (JCL) has been acknowledged as one of the promising candidates [24].

Parts of Jatropha plant, like wood, fruit shells, seed husks and kernels [25], are used to produce energy. Raw oil is the major resource obtained from Jatropha. Depending on the variety/ cultivars, decorticated seeds contain 40–60% oil [26–31]. The oil is utilised for many purposes, such as lighting, lubricating, making soap [32] and most importantly as biodiesel. Biodiesel from Jatropha comply with European biodiesel standards (**Table 1**).

Parameter	Jatropha oil
Density at 15 °C	0.920 g/cm^3
Viscosity at 30 °C	52 cSt
Flash point	240°C
Fire point	274 ± 3°C
Cloud point	9 ± 1°C
Pour point	4 ± 1°C
Cetane number	38
Caloric value	38.20 MJ/kg
Conradson carbon residue	0.8 ± 0.1 (%w/w)
Hydrogen	10.52 (%w/w)
Sulphur	0 (%w/w)
Oxygen	11.06 (%w/w)
Nitrogen	0
Carbon	76.11 (%w/w)
Ash content	0.03 (%w/w)
Neutralization number	0.92 mg KOH/g
Saponification value	198
Iodine number	94
Monoglycerides	Not detected
Diglycerides	2.7% m/m
Triglycerides	97.3% m/m
Water	0.07% m/m
Phosphorus	290 mg/kg
Calcium	56 mg/kg
Magnesium	103 mg/kg
Iron	2.4 mg/kg

Source: Giibitz et al. (1999).

Table 1. Chemical and physical properties of Jatropha oil.

There are approximately 24.60%, 47.25% and 5.54% of crude protein, crude fat and moisture, respectively, in Jatropha oil [33]. Both saturated and unsaturated fatty acids are present in the oil. The major saturated fatty acids are Palmitic acid (16:0) at 14.1% and stearic acid (18:0) at 6.7%, oleic acid (18:1) at 47.0% and linoleic acid (18:2) at 31.6%. The usefulness of Jatropha oil and its esters instead of petro-diesel has been reported [34]. The energy value of Jatropha seed oil (39MJ kg^{-1}) is higher than anthracite coal and is comparable to crude oil [35].

By mass, the shells bears about 35–40% of the dry fruit, that is, 60–65% of the seed weight [36]. There are approximately 42% husk and 58% kernel in a seed [25]. The gross energy value of Jatropha seed is 24 MJ kg^{-1} which is higher than lignite coal and cattle manure and is comparable to corn cobs [37].

The first step of oil extraction is the mechanical removal of the shell from the fruit. Jatropha seed shell contains cellulose (34%), hemicelluloses (10%) and lignin (12%) [25]. Approximately 11.1 MJ energy is driven from one (1) kg seed shell of Jatropha [35].Ash (4%), volatile matter (71%) and fixed carbon (25%) are the components of seed husk. Approximately, 16 MJ energy is driven from one (1) kg seed husk [36], which is comparable to wood.

Less energy expenditures and the prospect of using a cheap substrate make hydrogen (H_2) gas a lucrative source of future renewable energy. Lignocellulose biohydrogen can be produced by the fermentation of de-oiled Jatropha solid waste (DJSW) and Jatropha seed cake that contains lignocellulose [38–41]. Kuma and co-workers reported highest achievable cumulative hydrogen production (CHP) of 296 mL H_2 by the fermentation of de-oiled Jatropha waste under optimum conditions. The reported optimum conditions are; substrate concentration 211 g/L, pH 6.5 and temperature 55.4°C [40]. Lopes and co-workers produced 68.2 mL H_2/gVS_{iJSC} biohydrogen by dark fermentation of seed cake by a pure strain of the bacteria *Enterobacter aerogenes* without pretreatment of the substrate [41]. In the viewpoint of energy saving, it is significant.

2.2. Industrial use

The common use of viscous oil from Jatropha seed is for making soap [31]. The manufacturing of soft and durable soap from Jatropha oil becomes easy because of the high palmitic acid content and its hydrophobic nature. People in West Africa, Zambia, Tanzania and Zimbabwe are familiar with the use of Jatropha soap [42]. The presence of glycerine in Jatropha oil soap makes the white soap good for skin. It also have very good foaming [43] properties. Jatropha soap can be used for various skin diseases because of its medicinal properties [44]. The 36% linoleic acid (C18:2) content in Jatropha kernel oil is good for skin care [42, 45]. The oil is also an ingredient in hair conditioners [46].

Jatropha is rich in many phytochemical constituents. Alkaloids, coumarins, flavonoids, lignoids, phenols, saponins, steroids, tannins and terpenoids are found in different parts of this plant [47]. These components show anti-microbial [48], anti-inflammatory [49–51], healing, homeostatic [52], anti-cholinesterase [53, 54], anti-diarrheal [55–57], anti-hypertensive activities [58] and are anti-cancer agents [59, 60]. It is necessary to study the toxicity associated with these phytochemicals. The toxic effects could decrease its medicinal value.

The strong purgative activity of oil helps to cure skin diseases and to soothe rheumatic pain. It is also used in pesticides. The people in the Philippines have been using the dye obtained from Jatropha bark for colouring finishing nets, cloths and lines [61]. Another application of seed oil is in eczema treatment [62]. Manufacturing of soap and cosmetics from Jatropha derivatives (as an alternative to Karitee butter) is a non-energy application of Jatropha.

2.3. Other uses

From prehistoric days, Jatropha is used to make hedges. The advantage is that animals do not feed on it. Seed germinating plants bears taproots along with surface roots; Jatropha is a seed germinating plant, and it protects soil against erosion. It also act as a nutrient pump because the roots can uptake the leached down minerals and return them in the form of leaf fall, fruit debris and other organic remains.

The higher protein content (58.1% by weight) of Jatropha seed cake, after detoxification, when compared to that of soy meal (48%), makes it a valuable animal feed protein supplement. As it possesses most of the minerals nutrients— nitrogen, potassium, calcium, magnesium, sulphur, iron, phosphorus, zinc, copper and manganese, Jatropha seed cake is considered to be an excellent organic fertiliser [63, 64].

3. Limitation of Jatropha as a biofuel crop

– A good commercial variety with a higher yield and disease resistance is still lacking.

– High fluctuation of yield among trees.

– It requires proper irrigation and nutrients for fruiting, though it can survive on insufficient irrigation and nutrients.

– Relatively long gestation period: it requires 3–5 years to become commercially productive.

– The presence of toxic components limits its use as feed and therapeutic agents.

– Recent study reveals that Jatropha is susceptible to pests and diseases.

– Jatropha is sensitive to frost and water logging.

– Jatropha may be host for some diseases (cassava diseases).

– High viscosity of Jatropha seed oil limits its use in cool climate conditions.

– In certain environments, Jatropha may create weed problem.

4. Jatropha production challenges

4.1. Poor seed yield

Related experts suggest that the Jatropha seed yield of 4–5 Mg/ha/yr is needed for the commercial viability of the industry. If the usual seed yield of 3.75 Mg/ha with 30–35% oil content or 1.2 Mg/ha oil yield only then Jatropha would compete with soybeans (USA 0.38 Mg oil/ha) and rapeseed (Europe 1.0 Mg oil/ha) [65]. However, there is high flocculation of the unit seed yield and seed oil content of Jatropha. A number of authors reported that the low seed yield and the low seed oil content are the one of the most important barrier for commercial viability of Jatropha biodiesel industry [19, 66–69]. In India, a different location trial at diverse agro-climatic regions was conducted and the average seed yield was recorded as 0.5–1.4 Mg/ha/yr after 5 years of plantation [14]. A similar result was observed from plantation of 24 elite accessions with good plant architecture (height and branching pattern) in sodic soil [20]. In Belgium, the average seed yield was reported as 0.5 Mg seed/ha after 4 years of plantation, using the best known production techniques [70]. Recent assessment revealed that globally the average seed productivity of Jatropha is 1.6 Mg/ha which is equivalent to 0.475 Mg/ha/yr biodiesel productivity, which is not a safe position for the industry to be economically feasible. In South Africa, the highest seed yield was 0.35 Mg/ha after 5 years of plant growth [21]. A Jatropha silvi-pastoral production system in central-west Brazil where hybrid seeds were used, however, it could not ensure any significant seed yield, against the expectation of 2.4 kg/plant [22]. In Tanzania, a negligible gain at US$ 9 ha^{-1} with yields of 3 Mg/ha and a loss of US$ 65 ha^{-1} on lands with yields of 2 Mg/ha of seeds after 5-year investment [23] were obtained. In Panzhihua, China, Jatropha could not change local energy scenario and the industry has been confronted by a number of risk factors [71].

Developing of a higher yielding and more oil containing variety is one of the main effective solutions. However, a good commercial variety is still missing [72]. Zhang et al. [67] and Yu et al. [68] also point out that variety breeding is one of the main hurdles for Jatropha planting.

Actually, the current Jatropha breeding program is limited to conventional breeding and surveying of germplasm resources of wild Jatropha plants [67]. However, the study of modern biotechnology application on Jatropha improvement is limited [72]. Particularly, studies on cloning, expression and biological function annotation for Jatropha genes, which are responsible for economical traits, are largely absent.

The enhancement of unit seed yield of Jatropha for commercial use should be the main objective of cultivation. Therefore, the techniques of Jatropha cultivation refers to many field practices such as propagation, site preparation, tree density and canopy control, insects and diseases control, fertilization and irrigation management, cropping treatments [67, 68, 73]. Few studies on planting techniques and poor management for planting base limit large-scale plantation of Jatropha [68, 74]. However, there is limited research to demonstrate precisely and scientifically the impact of field operation on the seed yield of Jatropha. Moreover, there are no/a few detailed reports on field observation on the seed yield under different treatments of cultivation techniques. For example, data on tree density for Jatropha cultivation, canopy pruning intensity and frequency, insecticide effect as well as fertilization and irrigation efficiency are largely absent in the literature.

4.2. Consider as low impute crop

J. curcas is believed as a low input crop because of its ability to grow on barren land. However, it needs adequate nutrients as fertilizer and rainfall or irrigation for growing as a productive crop. On the other hand, excessive fertilization and irrigation may cause vegetative growth (biomass production) at the cost of fruit production. Moisture and nutrients have larger influence on the seed yield and oil productivity from the plantation on marginal lands. The plant growth and the seed yield of *J. curcas* were significantly increased under irrigated conditions as compared to non-irrigated conditions [9, 14]. It was observed that there was 750 kg/ha yield under irrigated conditions at the same time only 450 kg/ ha was recorded under rainfed conditions from 3-year-old plantations [75]. Application of nitrogen and phosphorus increased the growth, seed yield and oil yield of *J. curcas* [76]. Furthermore, another report by BAIF Development Research Foundation showed that there was about 500 kg/ha seed yield under rainfed conditions in the fifth year of plantation. However, after regular irrigation of the same plantation, in next year the seed yield was recorded about 1200 kg/ha [77].

The systematic studies for yield improvement, the agronomy (especially the irrigation and nutritional requirements) in different agro climatic conditions have not been adequately addressed, despite advocacy for large-scale plantation of *J. curcas* [78].

4.3. Pest and disease susceptibility

Control of insects and diseases is particularly one of the most important technical issues which could seriously shape Jatropha cultivation (**Figure 3**). Though it was claimed that Jatropha is free of pests and diseases, the current study do not support the claim. Recent studies reported that the plants were susceptible to viral infection (Cucumber mosaic virus), insect attack, rodents, powdery mildew, leaf spots, insect defoliations and fungal diseases of the soil [14, 21]. In Belgium, leaf miner *Stomphastis thraustica*, the leaf and stem miner *Pempelia morosalis* and the shield-backed bug *Calidea panaethiopica* are the major pests affecting Jatropha [79]. Fruit sap sucking predators *Scutellera perplexa* [80] and *Maconellicoccus hirsutus* have recently been investigated in India [81]. These infections caused approximately 60–80% damage to the standing Jatropha crop at different study sites [14, 79–81].

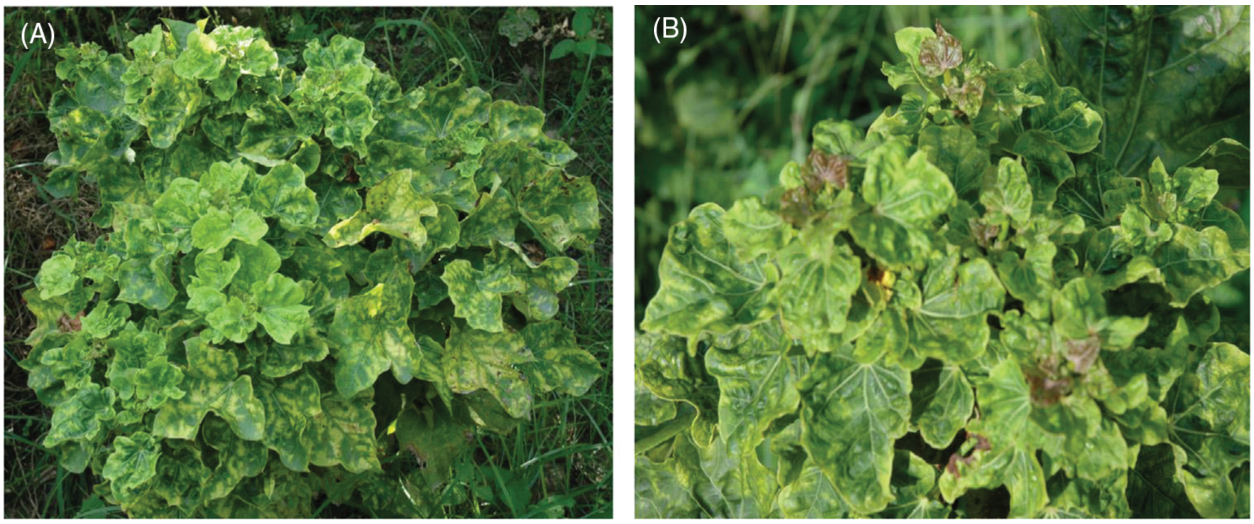

Figure 3. The photographs (A and B) show viral incidence in Jatropha.

Moreover, monocropping could result in the spreading of insects and diseases. In Panzhihua, China Yu and co-workers found 24 species of insects and diseases that are affecting Jatropha

[82]. Wu and co-authors reported eight diseases and seven species of insects on Jatropha in the dry-hot valley of Yunnan Province [83]. Jatropha monoculture expansion may spread insects and diseases.

4.4. Jatropha breeding objectives [72]

- Dry matter (increased fruit and carnal size) accumulation in fruits rather in cost of vegetative growth.
- Higher female flowers ratio per inflorescence for more fruits.
- Flowering and fruit maturity synchronizing for mechanisation of harvesting.
- Bigger seeds and more oil contents.
- More branching to produce more flowers, fruits and seeds.
- Oil quality improvement.
- Development of non-toxic variety for safe use.
- Disease and stress tolerant cultivar development.
- Improve plant architecture for deeper and smaller rooting.

5. Oil extraction challenges

Jatropha seeds contain 40–60% of oil depending on the variety [18, 84]. The first step of oil extraction is the removal of shells from the seeds after collecting the ripe fruits from trees. Seed oil can be extracted manually, mechanically, chemically and enzymatically. The oil extraction process is shown in **Figure 4**. Oil can be extracted by mechanical pressure, solvent extraction and enzymatic degradation of kernel. Mechanical extraction yields about 90% of total oil from the seed [85]. Solvent and enzymatic extraction yield almost 100% of oil from the seed. However, these are complex processes and take long time. Solvent extraction involves handling of large volume dangerous chemicals. Commercially suitable enzyme(s) is still not available for enzymatic extraction of oil from seed kernel [86, 87] till date.

In the mechanical process, a machine is used to exert pressure on seeds for the removal of oil. After cleaning and checking, the seeds are fed into the hopper of the machine. For Jatropha seed 0.41 L of oil is extracted from 1 kg. Mechanical parameters and pretreatment of seeds affect oil yields. The effects of treatment and physical parameters on the oil extraction are shown on **Figure 5**. The amount of oil that can be recovered from the seeds is affected by:

- *Throughput*: It is the amount of seed crashed per hour (kg/h). The higher throughput recovers less amount of oil per kg of seeds, because of short time exposure of seeds to pressure. It can be regulated by altering the turning pace of the screw throughput.

- *Oil point pressure*: It is the amount of pressure necessary to start oil flow from the seeds. If it is possible to reduce the oil point pressure, the oil extraction becomes easier.
- *Pressure*: The more the pressure, the more the oil recovered from the seeds. But oil recovery at high pressure brought more solid particles with oil. It makes the removal of solid particles more difficult. A pressure range of 50–150 bar is considered as the optimum operating pressure for engine-driven oil extraction.
- *Nozzle size*: A smaller pore causes higher pressure and therefore a higher oil yield. An ideal nozzle size is needed for smooth operation.
- *Hull content of the seeds*: Less energy should be used for pressing seeds so that there are no hull fibres in the crude oil. However, it appears like paste inside standard expellers, which sticks to the worm and keeps rotating along with it.

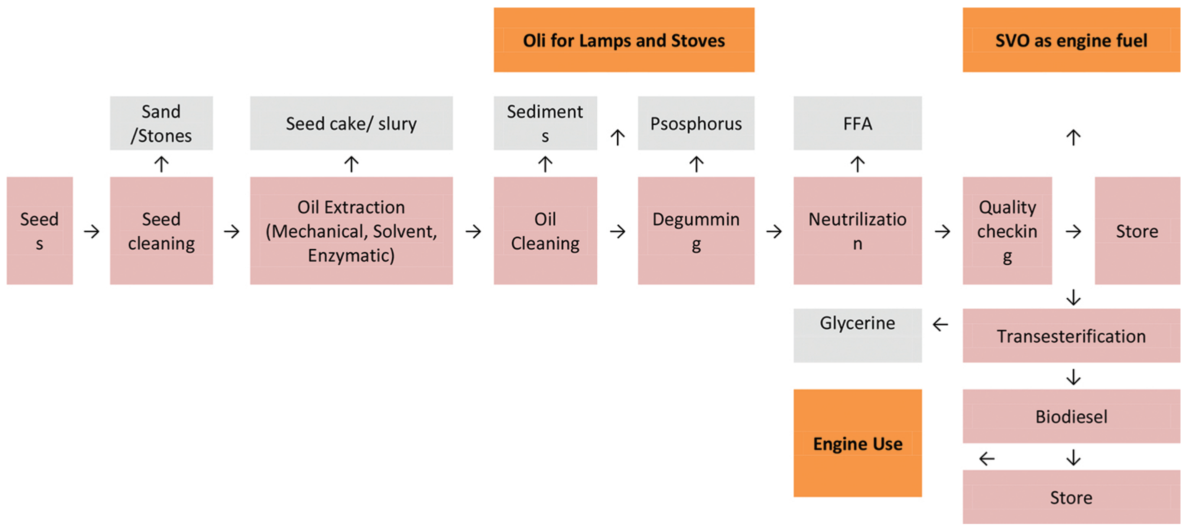

Figure 4. Oil extraction steps and use.

Pre-treatments		Oil Yield	Pressure	Temperature	Throughput	Energy/litter
heating	▲		▼	▲		▼
boiling		▼	▲	▲		▲
flaking		▼		▼		▼
moisture content	▼	▲	▲	▲	▼	▲
hull fraction	▼	▼	▼	▼	▼	▼
Mechanical factors						
RPM	▼	▲	▲		▼	▲
restriction size	▼	▲	▲	▲		▲

Figure 5. Pre-treatment and mechanical factors effect on seed oil recovery.

The mechanical method is easier and less expensive but produces less oil (8–9%). Heat is generated during the process that affects the quality of biodiesel. A high efficient oil recovery (90–98%) technique, solvent extraction, is the most widely used. However, high energy input and toxicity of solvent used are major disadvantage of this technique. Enzyme-based techniques may be the solution [88]. For extraction of oil from *Jatropha* seeds, aqueous enzymatic oil extraction (AEOE) is a promising technique. Plant cell walls are composed of a complex chemical structure. Enzymes that present in the system break cell walls and oil bodies and accelerate oil recovery. This eco-friendly process does not produce volatile organic compounds as atmospheric pollutants. Prolonged reaction time is the major disadvantage associated with AEOE. Moreover, suitable commercial enzyme is not available till date. Winkler et al. [87] studied enzyme supported oil extraction. They used alkaline protease, protease in combination with hemicelluloses and/or cellulose. Alkaline protease treatment produces 86% oil.

Ahmad et al. [89] isolated a bacteria marked MB4, which produces xylanases that enhanced the extraction yield of Jatropha oil. The advantages offered by this process are: protein in the residue can be further processed for other applications, no purified enzyme preparation is needed, and the resulting oil can be used for biodiesel production. Immobilization of lipase has gained immense potential in the biofuel industry mainly to reduce the production costs and to make the method more economical [90].

6. Conversion challenges

There are two types of methods, which are generally used for conversion of hydrocarbon fuels from renewable feedstock. One is the thermochemical process and another is the biochemical process. The thermochemical process is the conversion of biomass to hydrocarbons in the presence of high temperature and pressure. In the biochemical conversion process, biomass is converted into carbohydrates over some steps by the method of fermentation using enzymes or micro-organisms [91]. The thermochemical conversion can be carried out mainly by transesterification, pyrolysis, microemulsion, esterification, gasification, etc. Among these processes, pyrolysis and transesterification are the promising methods, which are used to produce Jatropha biofuel, mainly biodiesel and bio-jet-fuel. Details of these processes are discussed below.

6.1. Transesterification

Transesterification, also called alcoholysis, is the reaction where the oil converts into its corresponding fatty ester [92, 93]. This is a similar process to hydrolysis but here, alcohol is used instead of water. So, transesterification is the organic reaction where one ester transfer into another ester by interchanging the alkoxy moiety. The basic reaction involved in transesterification is shown in **Figure 6**. This reaction is used to decrease the high viscosity of triglyceride. Due to the reversible nature of this reaction, extra alcohol is used to move the equilibrium towards the product. A catalyst is used to promote the reaction rate and the product yield [94]. Two types of catalysts are used in the transesterification reaction. The acid catalyst makes the carbonyl group more reactive by donating a proton while the base catalyst remove a proton from alcohol to make it more reactive [93].

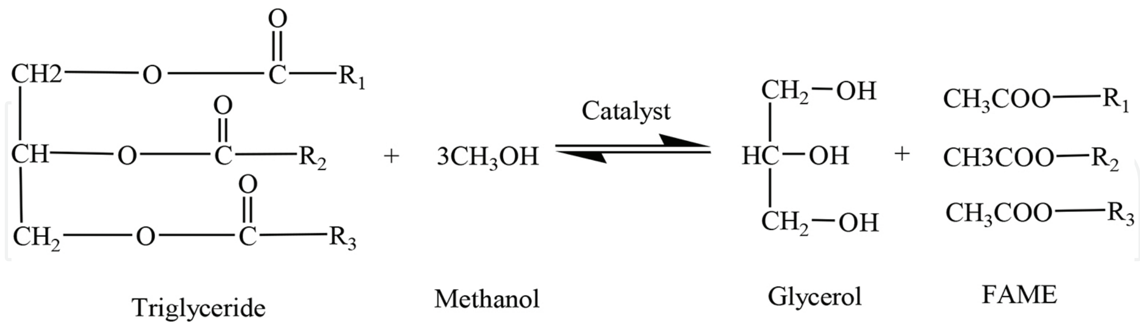

Figure 6. Catalytic transesterification of triglyceride.

The transesterification process of Jatropha oil produces mono fatty acid alkyl esters and glycerol as the by-product. In this process, methanol is the alcohol used due to its low price, low temperature reaction, minimum reaction time and high yield of fatty acid methyl esters [95]. This reaction is affected by several factors, such as molar ratio of glycerides and alcohol, reaction temperature, time, catalyst and also the free fatty acid content and moisture content in the Jatropha seed oil. Generally, the homogeneous base catalysts, NaOH and KOH, are used because of their higher yield and quality fatty acid methyl esters (FAMEs) [96]. However, homogeneous base catalyst for transesterification of Jatropha oil associates some problems. It is very difficult to separate the catalyst from the product and the purification step produces a large amount of alkaline wastewater. Treatment of this water also increases the production cost [97]. Because of the presence of the higher free fatty acid content and the moisture content in Jatropha oil, the base catalyst induce saponification reaction which decrease the production yield [98]. To overcome this problem, an acid catalyst can be used in transesterification of Jatropha vegetable oil, but with the acid catalyst, the reaction requires more oil-methanol molar ratios and the reaction will be very slow [99]. Another possible solution to overcome this problem is a two-step procedure for the treatment of Jatropha oil. First step is esterification of free fatty acid and the second step is transesterification of Jatropha oil triglyceride [100]. But this is also not cost effective. Instead of a homogeneous catalyst, a heterogeneous catalyst is a better option for transesterification of higher FFA containing vegetable oil because it can result in good conversion and a high yield of FAME with optimum reaction conditions [101]. Many researchers recommended the heterogeneous catalysts for transesterification of vegetable oil in their investigation [99, 102–111].

6.2. Pyrolysis/thermal cracking

Pyrolysis or cracking of vegetable oil is one of the promising routes to produce biofuel (biodiesel and bio-jet-fuel) because of the straight chain alkanes and high cetane number of the product [112–114]. Pyrolysis is defined as the thermal conversion of vegetable oils by heat in absence of air in favour of a catalyst into alkanes, alkenes, aromatics, carboxylic acids and little amounts of gaseous products [115]. When compared with transesterification of Jatropha

http://dx.doi.org/10.5772/64979

vegetable oil for producing biofuel, the hydrocracking process needs a higher energy and temperature (280–300°C) [116] but the pyrolysed products have a higher cetane number and oxidation stability. Catalytic pyrolysis increases the yield of product by breaking large molecules, and also improves the quality of the product (biofuel).

Catalytic cracking of vegetable oil is a three-step mechanism. First one is the removal of oxygen by C═O bond hydrogenation, then C─O bond rupture and finally C─C bond breaking with the aid of a catalyst. The cracking reaction may occur by different routes such as: hydrodeoxygenation, decarboxylation and decarbonylation, which are shown in **Figure 7**. Each route produces shorter and straight chain hydrocarbons with the removal of water, CO, CO_2, etc. Catalytic cracking of Jatropha oil in the presence of different heterogeneous catalysts shows better result. The activities of different catalysts in cracking of Jatropha oil for producing biofuel are investigated under different conditions.

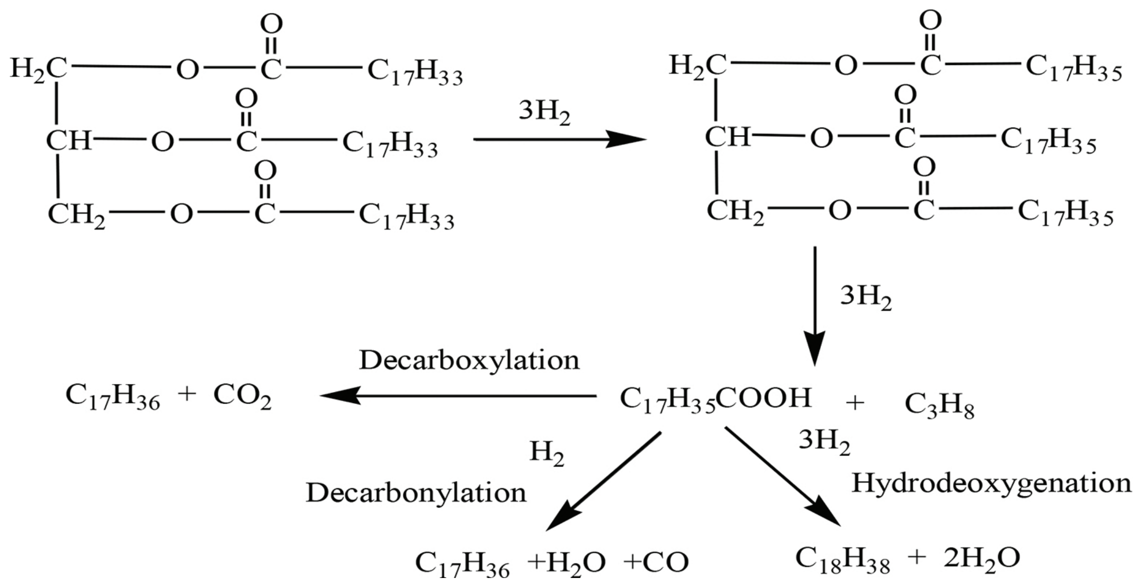

Figure 7. Catalytic cracking of triglyceride.

Today, the conventional catalysts which are used to crack vegetable oil are mainly sulphided silica, alumina-supported Ni-Mo, Co-Mo or Ni-W [117–122]. So using these catalysts needs the addition of sulphur containing compounds which are responsible for the production of sulphur residue with the end product and causes greenhouse emission like H_2S and also corrosion problem. Moreover, the noble metal catalysts are more active but the disadvantages with them are high price and rarity, as well as they are responsible for catalyst poisoning and impurities [123]. Recently some novel metal catalysts have been developed for hydrocracking of Jatropha oil. PtPd/Al_2O_3 and sulphided NiMoP/Al_2O_3 at 330–390°C temperature and 3 MPa pressure [124]; Ni/H-ZSM-5 [125]; sulphided form of Co-Mo/Al_2O_3, Ni-W/SiO_2–Al_2O_3; and Ni–Mo/Al_2O_3 have been developed for producing biofuel from Jatropha oil. Among the other catalytic systems, the homogeneous solid base catalyst is more beneficial for hydroprocessing Jatropha oil because of its reusability, low cost and high selectivity [126]. But the base catalyst produces soap with FFA and it needs a high purity Jatropha oil which is the main obstacle [127].

The major problems with Jatropha bio-jet-fuel are its freezing point and low yield. The freezing point of Jatropha hydrocarbon produced by catalytic cracking is higher than zero degrees whereas the freezing point of conventional jet fuel is less than −40°C [128–130]. To overcome this problem, a new catalyst system has to be designed for hydroprocessing Jatropha oil. There are many advantages of using metal supported on microporous zeolite catalysts for hydrocracking Jatropha oil due to the versatile characteristics of zeolite [131]. Zeolite catalysts have ion-exchange abilities with high porosity, broad surface area and concurrent-base character [132]. It can solve the diffusion limitation and increase the production yield due to its unique structure. For cracking reactions, high temperature (280–300°C) and pressure are necessary, which increase the production cost. So it is most important to select and improve the non-sulphided metal supported zeolite catalyst as well as the selection of optimum conditions (temperature, pressure and reaction time) for hydrocracking of Jatropha oil to produce diesel and jet-fuel range hydrocarbons.

The mostly used zeolites for cracking reaction are Zeolite Y, Meso-Y, H/ZSM-5, Na/ZSM-5, Ni/ZSM-5, Ru/ZSM-5, Zeolite β, SAPO-11, SAPO-34, Ni/SAPO-11, ultrastable-Y zeolite (USYZ), rare earth-Y zeolite (REY), Bentonite P-140, SBA-15, MCM-41, etc. [133–141]. The catalytic activity of several zeolites depends on its structure, shape and size of the substrate, polarity and the reaction parameters such as temperature, pressure, time, etc. A high reaction temperature shows the high activity of zeolite. Some investigations showed the cracking result of different vegetable oils with different supported zeolite catalysts. The cracking of sunflower oil with the CaO/SBA-14 catalyst under 160°C temperature and 5 hours reaction time showed 95% biodiesel yield [142], whereas SAPO-11 showed 83–90% yield on the treatment of palm oil under 7 wt% Ni loading, 493°C temperature and 2 MPa H_2 pressure for 6 hours [117]. On the other hand, Mesoporous-Y zeolite showed 40.5% bio-jet-fuel yield at 400°C temperature for 3 h cracking [138].

7. Use challenges

7.1. Crude oil use

Non-edible Jatropha oil is the promising alternative as bio-energy for diesel and jet engine. But, due to the high viscosity, large molecular mass and chemical structure of Jatropha oil, it cannot be used directly to the compression ignition (C.I.) engines for long time. From the study it is very clear that using Jatropha oil directly can cause some problems to the engine [143–145]. The main problems are pumping, burning and atomization with the injector system of compression ignition engine. Unburned Jatropha oil can distort the injector nozzle, stick to the ring and damage the cylinder of the diesel engine [146, 147]. It also makes the emission of particulate substance such as smoke, unburned hydrocarbon and carbon which affect human health and pollute the environment [146]. Hence, the better way to use Jatropha oil directly to the diesel engine is by the reduction of its viscosity by means of blending *Jatropha curcas* oil with diesel oil in different proportions.

There have been some investigations to the use of Jatropha oil blends in diesel engines. At different proportions of Jatropha oil and diesel blends, it shows different oil properties and engine performance. **Table 2** [143, 146] shows the different properties of diesel and diesel/oil blends in different proportions. From the data it is clear that the viscosity and density gradually decreased by decreasing the amount of crude Jatropha oil in the diesel/oil blend. It is observed that the oil blend containing more than 20% Jatropha oil have high viscosity compared to the maximum viscosity limit of the diesel engine. So, the viscosity needs to be reduced more to make the blend usable for diesel engine. Where the permeable limit of fuel viscosity for diesel engine is maximum 870 kg/m^3, the viscosity of oil/diesel blend for 2.6:97.4 proportion is 868 kg/m^3 which is very near to the maximum limit. But, addition of Jatropha oil with diesel decreases the exhaust gas temperature. So, only a small portion (about 2.6%) of Jatropha oil can be used with diesel fuel as the ignition-accelerator additives.

Jatropha oil:diesel	Pure Jatropha	70:30	50:50	30:70	20:80	2.6:97.4*	Pure diesel
Density (kg/m^3)	917	900	891.5	881	876	868	866
Viscosity (cSt) at 30°C	36.9	23.45	17.5	9.8	6.9	5.9	5.7
Exhaust gas temperature (°C)	210	230	245	252	260	275	280
Flash point (°C)	99	–	94	–	90	88	86
Pour point (°C)	−3	–	+6	–	+12	+15	+15
Specific gravity	0.918	–	0.892	–	0.877	0.869	0.867
Calorific value (Mg/kg)	42	–	43		44.2	45.2	45.9

Table 2. Different properties of Jatropha oil-diesel blends.

7.2. By-product: seed cake and glycerine

Jatropha curcas seed oil is the most offering alternative source of feedstock for biofuel industries. From Jatropha biofuel plant, some by-products are produced. The main by-products are seed cake and glycerine. To make sustainable and economically viable industry, it is necessary to use by-products properly. But there are some problems to recover and use these by-products directly. Jatropha seed oil and seed cake contain 58–64% protein with high nutritional value [148]. But, they also contain some toxic ingredients such as: phorbol esters, lectins, trypsin inhibitors, phytate, saponins, tannins, etc., which make them non-edible for human, fish, goat and mice. Also, the process to recover glycerine from biofuel is not easy. So, proper steps should be taken for using these by-products.

Seed cake: Due to the presence of toxic components, Jatropha seed cake cannot be used as a feed meal for human, fish, goat, chicken and rat. Phorbol ester is responsible for cancer, skin irritation, tumour promotion and purgation [149]. Lectins cause haemorrhagic spot and trypsin inhibitor causes adverse effect in monogastrics [150]. So, before using seed cake as an animal feed it needs to be detoxified. Lectins and trypsin inhibitors are heat sensitive and they decrease during biofuel processing at about 160°C. But phorbol ester decreases only 5% at high temperature. By increasing the digestible organic matter and metabolizable energy, heat treatment increases the nutritive value of *Jatropha curcas* seed meal [151]. So, the main issue is to neutralize the toxic phorbol ester from Jatropha seed meal before use. **Table 3** [151, 152] shows the different toxic components present in Jatropha and soybean meal.

Toxic component	Toxic variety	Non-toxic variety	Soybean meal	Result of heat treatment
Phorbolester (mg/g kernel)	2.70	0.11	–	5% decrease
Lectins (mg/ml assay)	102	51	0.32	Decrease
Trypsin inhibitors (mg/g meal)	21.1	26.5	3.9	Decrease
Phytate (% in meal)	10.1	8.9	1.5	No change
Saponins (%)	2.6	3.4	4.7	No change

Table 3. Toxic components present in Jatropha curcas oil and seed cake.

There have been several methods to detoxify the toxic phorbol ester from Jatropha oil and seed kernel. Some of them are fungal isolation, γ-irradiation, adsorption, plasma application, ozonation, etc. During the Jatropha oil refining and purification processes about 55% phorbol ester can be removed by bleaching and de-acidification step but degumming and deodorizing step cannot remove phorbol ester [151]. About 44% phorbol ester can be removed by chemical treatment by using $NaHCO_3$, whereas the combination of chemical treatment and heat treatment can remove 56% and the combination of chemical treatment and ozonation can remove up to 75% phorbol ester from *Jatropha curcas* seed oil and seed meal [153]. Gamma irradiation can remove 71.35% of phorbol esters at 50 kGy absorption dose. But this method takes long time, high temperature and high dose of gamma irradiation which is not economic. On the other hand, fungal isolation can remove 97.8% of phorbol esters from Jatropha seed and oil [154]. Among all the processes, the adsorption process is more effective to detoxify Jatropha oil phorbol ester and this process can remove up to 99.5% phorbol ester present in the Jatropha seed oil. Un-detoxified oil contains 2.70 mg/g phorbol ester. After detoxification by the adsorption process, Jatropha oil contains 0.02 mg/g phorbol ester, which is lower than permissible limit (0.09 mg/g) [152, 155].

In the adsorption process, the one-time adsorption carried out with 3.2% (w/v) bentonite 200 as the adsorbent at 32°C temperature, 100 rpm stirring rate and 15 min adsorption time can remove 98% phorbol ester. Two-time adsorption with 0.8% (w/v) bentonite 200 under same conditions can remove 99.50% phorbol ester [152].

Glycerine: Glycerine is the major by-product of Jatropha biofuel processing plant. So, the recovery and proper use of this product is more beneficial for the Jatropha biofuel project. But, the recovery of glycerine from biofuel is not an easy process. Traditionally, glycerine is recovered from biofuel by washing with water. In this process, water is mixed with the biodiesel, agitating the mixture gently, allowing the mixture to separate the several phases and finally glycerine is extracted from the water phase [156]. But, this process is not favourable because water causes many problems when used to wash biofuel. Washing of biofuel needs the use of deionized water, produce large amount of wastewater. This water can degrade the biofuel by hydrolysis and it can increase the processing time with multiple drying, multiple washes and water-biodiesel separation steps [157]. The suitable alternative to recovery glycerine from the biofuel is the adsorption with a bed of ion exchange resin [158]. But this process is not established yet. Recovery of glycerine from biofuel by ion exchange resin is the combination of four steps: filtration, physical adsorption, ion exchange and removal of soap by glycerine affinity.

8. Alternative of Jatropha

There are many potential non-edible oil-rich plants in almost every country (mostly tropical and subtropical). Mostly they are wild and naturally growing. They may or may not have yet been explored for oil producing potential. In India, 11 tree species (*Garcinia indica, Azadirachta indica, Hevea brasiliensis, Calophylluum inophyllum, Madhuca indica, Mesua ferrea, Mallotus philippines, Ricinus communis, Pongamia glabra, Salvadora* and *Shorea robusta*) are largely distributed that have biodiesel producing potentials [17]. *Camelina sativa, Gossypium hirsutum, Cynara cardunculus, Abutilon muticum, Simmondsia chinensis, Passiflora edulis, Aleurites moluccana, Carnegiea gigantea, Pachira glabra, Croton megalocarpus* and *Terminalia bellirica* have high content of non-edible oil in their seeds [159]. These plants may also be explored for their suitability to meet the blending requirements rather than focusing on a single candidate (Jatropha).

9. Lifecycle assessment (LCA) of the Jatropha biofuel

Environmental impact of biofuels is determined by lifecycle assessment [160, 161]. The environmental flows throughout the lifecycle stages of a product or services are evaluated by LCA [162]. The four interacting individual phases—scoping, inventory analysis, impact assessment and interpretation—are the basic of LCA study (ISO, 2006). International Organization for Standardization (ISO) regulates it as 14040:2006 and 14044:2006 standards.

Jatropha cultivation, oil extraction, conversion of seed oil into biodiesel and biodiesel use are four major phases of the Jatropha biodiesel system. **Figure 8** shows the system boundaries of the Jatropha biodiesel. The flow processes, inputs and outputs in the Jatropha biodiesel system are summarized in **Table 4**. Energy balance, global warming potential (GWP), and land-use impact, net energy gain (NEG), net energy ratio (NER), ecosystem structural quality (ESQ) and ecosystem functional quality (EFQ) are most relevant impact categories of LCA systems [161, 163]. The data on LCA of Jatropha biodiesel is not sufficient though there are some reports on the LCA methodology [163–167] and LCA [168, 169] for Jatropha biodiesel.

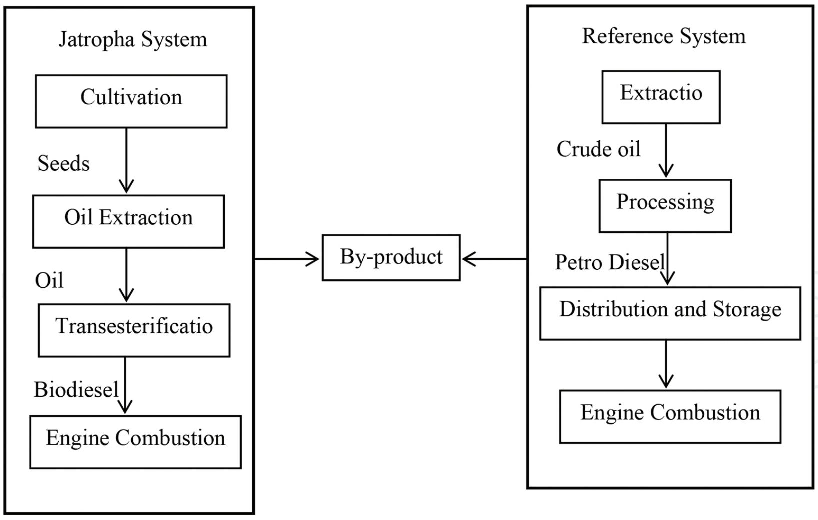

Figure 8. System boundaries of the Jatropha biodiesel system.

Phase	Processes	Inputs	Products	By-products
(a) Cultivation				
Seedling production	– Seeding in nurseries	– Energy, machines, infrastructure	– Air emissions	–
Plantation establishment	– Planting cuttings – Transplantation – Direct seeding – Land preparation	– Energy, machines, auxiliaries	– Air emissions – Standing biomass – Seeds	–
Plant management	– Pruning, canopy management, fertilising, irrigation, harvesting	– Energy, machines, infrastructure auxiliaries	– Air emissions	– Woody cuttings
(b) Oil extraction	– Mechanical – Solvent-based	– Energy, machines, infrastructure, auxiliaries	– Air emissions – Raw oil – Wastewater	– Seed cake – Fruit shells
(c) Transesterification	– Catalysis – Transport of biodiesel	– Energy, infrastructure	– Air emissions – Biodiesel – Wastewater	–
(d) Use	– Combustion		–Air emissions	–

Table 4. Flow processes, inputs and outputs of the Jatropha biodiesel system.

Jatropha is believed to be a suitable crop for wastelands with low inputs. However, an industry cannot be established depending on unreliable feedstock supply based on low-input agriculture. Thus, fertilizers, irrigation and pesticide use will be unavoidable in commercial Jatropha production. Furthermore, transesterification, the major conversion technology, is the major contributor to GHG emissions and energy consumption. To be a suitable alternative of petro-diesel in terms of mitigation of climate change, Jatropha biodiesel needs to be supported by lifecycle data. The environmental benefits of Jatropha biodiesel in comparison to petro-diesel is in doubt [169, 170]. Following measures can improve lifecycle performance of Jatropha biodiesel:

a. Use of bio-fertilizers for Jatropha cultivation and optimization of inputs

b. Irrigation by consuming minimization and/or low-energy

c. Transesterification processes optimization

d. Water footprint consideration

10. Contribution and expectation from Jatropha

With enormous potentials on social, agricultural, environment, sustainable energy production and industrial fronts, Jatropha is attracting interest from researchers and policy makers. Research showed that Jatropha seed has 40–60% oil content with a productivity of 0.1–12 tons per ha [32, 63]. Yields of both fruits and oil depend on species, accession, soil, climate and agronomy [66, 171]. A seed yield of 4–5 mg/ha/yr is expected for the commercial viability of the Jatropha-based biofuel program. With 30–35% oil content and an average seed yield of 3.75 mg ha/yr Jatropha is economically more beneficial to the average yield profile of soybeans and rapeseed [19].

However, the actual seed production of Jatropha in field conditions was poor than expected [20–22]. The reported yields of Jatropha under field conditions in India, Belgium, South Africa and Tanzania are 0.5–1.4 mg/ha/yr, 0.5 mg/ha/yr, 0.35 mg/ha/yr and 2 mg/ha/yr, respectively [23]. The less productivity is because of unavailability of suitable high yielding varieties, large-scale plantation without evaluating the genetic potential of planted materials, consideration of Jatropha as no/low input crop and lack of knowledge on agronomy.

Jatropha seed cake is an excellent source of protein. To add commercial value it is expected to utilize the press cake as an animal feed protein supplement. The presence of toxic compounds hinders its utilization for this purpose. The discovery of non-toxic Jatropha varieties and the detoxification process of toxins are an advantage. Many biological active chemical compounds are extracted from bark, leaves and roots that are expected to be used in the pharmaceutical industry. However, toxicity must be studied before the use of Jatropha products as therapeutic agents or medicines.

Oil from Jatropha has been used as cooking fuel and in soap and cosmetic manufacturing in ancient times. It is reported that Jatropha oil can be utilized as a fuel with diesel engine directly or with slight modification of the engine. Jatropha oil can be converted to biodiesel by chemical reaction called transesterification. This biodiesel can be used by blending with petro-diesel. High viscosity is the major problem of using Jatropha seed oil as fuel.

11. Technological intervention for Jatropha improvement

Jatropha bears multi-dimensional potentials [172]. But it is still behind to compete in commercialization. High yielding Jatropha varieties are not found yet. Lack of agronomic knowledge, unawareness or knowledge gap of farmers and the common belief that no impute crop renders Jatropha's productivity [2, 173]. It requires extensive searching for natural germplasms and systematic breeding programs for genetic improvement. The success of breeding depends on the availability of diverse germplasms [62]. However, some study showed narrow genetic diversity among the worldwide population [174–179]. It limits the success of conventional breeding. Inter-species and inter-generic hybridization, haploid breeding (anther, pollen, ovary culture), somaclonal and germaclonal variation and mutation breeding are biological techniques that have proven records for variation creation and breeding of many important crops. For Jatropha there are some reports on organogenesis only. Other technologies are still unexplored. Genetic resources technology, i.e. marker-assisted selection (MAS), molecular breeding, genomic selection, genome-wide association studies and genetic engineering have been used with confident for many crop breeding programs. Jatropha genomic technology research is still far behind in comparison to other important crops though some reports are available on that [180–186]. Now it is time to explore full potentials of Jatropha by using modern technologies.

12. Conclusions

It is very crucial to find reliable renewable energy sources for healthy economy and environment. Jatropha is a promising candidate of renewable energy as it has interesting characteristics and non-competition with food. A number of big projects has been launched and completed. However, the result is disappointing. Unavailability of good commercial variety, considering low impute and disease resistance crop, knowledge gap, lack of basic research and theoretical assumption mostly without scientific and technological backup are the major reasons of the failure. Thus, Jatropha biofuel industry is confronting a number of challenges.

Efficient oil extraction methods form Jatropha seeds need to be explored. Mechanical pressing is commonly used but it is poor yielding and also affects the oil quality. Solvent extraction needs to use many hazardous solvents. Enzymatic process is good but has a slow reaction rate. It needs to find/develop suitable enzymes and to increase the reaction rate. Conversion of crude Jatropha oil to biofuel (biodiesel or jet fuel) is another challenge. Transesterification and thermal cracking are commonly used. It needs to develop environmentally friendly catalyst with high conversion efficiency. By-product utilization can reduce waste management cost and also add economic value. Seed oil cake and glycerine are the main by-products of the Jatropha industry. It needs appropriate method of glycerine recovery and detoxification method of seed cake for safe use.

Plant breeding in application of biotechnology is the gateway of crop improvement (yield and quality). Diverse germplasm is the basis of a breeding program. Accumulation and utilization

http://dx.doi.org/10.5772/64979

of specialised but scattered knowledge is important for Jatropha improvement. Major Jatropha cultivating countries—India, China, Malaysia, Indonesia, Brazil, Mexico and South Africa—can establish an international organization. To design a strategic breeding program for Jatropha improvement, the researchers can share their learning gained by several years of experience.

Biotechnology application in Jatropha breeding is far behind as compared to some other crop. Somaclonal and germaclonal variation are created by *in vitro* mutagenesis, *in vitro* micropropagation, anther and microspore culture, ovary and ovule culture, protoplast culture, nucleolus culture, endosperm culture, and somatic embryogenesis. It needs to explore them because these techniques have proven record for crop improvement. There are a few works on Jatropha genome though; it is still far behind in comparison to other agricultural systems.

Though there are some biotechnology studies, however, Jatropha genome work is far behind than the model and other agricultural systems. Researchers require a high density linkage map for the determination of the association of markers with high oil yield. The *J. curcas* genome is very small (ca.400 Mb). Thus, marker-assisted selection, genome-wide association studies (GWAS) and genomic selection (GS) could be even more attractive. A well-assembled reference genome of Jatropha is indispensable for these applications. Increasing female flowers in inflorescence, reducing toxins and increasing resistance are on priority.

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