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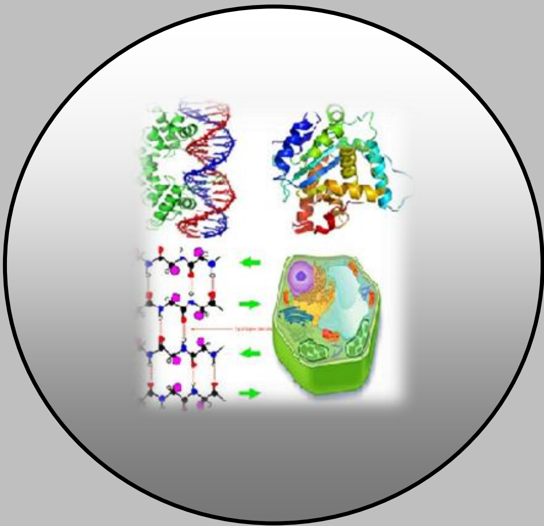

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REVIEW ARTICLE

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Production of Biodiesel from *Jatropha curcus* L: An Updated Review

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ABSTRACT

Biodiesel, a promising substitute as an alternative fuel has gained significant attention due to the predicted shortness of conventional fuels and environmental concern. Biodiesel has attracted considerable attention during the past decade as a renewable, biodegradable and non-toxic fuel alternative to fossil fuels. Biodiesel can be obtained from vegetable oils (both edible and non-edible) and from animal fat. Jatropha curcas L, a multipurpose plant, contains high amount of oil in its seeds which can be converted to biodiesel. The utilization of liquid fuels such as biodiesel produced from Jatropha oil by transesterification process represents one of the most promising options for the use of conventional fossil fuels. In this paper, we give an overview of the currently available information on the different process steps of the production process of bio-diesel from JSL. The genus Jatropha is distributed throughout the tropics and sub-tropics growing in marginal lands and is a potential biodiesel crop worldwide. The plants can prevent soil erosion, grown as a live fence and used as an alternate commercial crop. The seed oil can be used as a feed stock for biodiesel. Alternatively, Jatropha oil is used in soap, glue or dye industry. The seed cake is rich in nitrogen and phosphorus, and can be used as manure. All parts of the plant including seeds have medicinal properties. However, the toxic components of the seed need immediate attention and efforts are needed to genetically modify Jatropha seed toxins to useful and non-toxic components through genetic transformation. The values obtained from the Jatropha methyl ester is closely matched with the values of conventional diesel and can be used in the existing diesel engine without any modification. The objective of this review is to give an update on the Jatropha plant, the production of biodiesel from the seed oil and research attempts to improve the technology of converting vegetable oil to biodiesel and the fuel properties of the Jatropha biodiesel.
Keywords: Bio Diesel, Jatropha curcas, Alternative Commercial crop, Genetic Transformation and Transesterification.

INTRODUCTION

Jatropha curcas L. is a multipurpose small tree or large shrub and is found throughout the tropical region. *J. curcas* is a tropical species native to Mexico and Central America, but is widely distributed in wild or semi cultivated stands in Latin America, Africa, India and South-East Asia. In India, Portuguese Navigators introduced it in the 16th century. It occurs in almost all parts of India including Andaman Island and generally grown as live fence. It is well adapted to arid and semi-arid conditions. JSL is a vigorous, drought and pest-tolerant plant and unpalatable by animals. It is planted in tropical countries principally as a hedge, protecting cropland from the cattle, sheep and goats (Francis et al., 2005 and Openshaw, 2000). JSL is a diploid species with 2n = 22 chromosomes.

Jatropha genome size (416 Mb) (Carvalho et al., 2008) is about equal to rice genome (400 Mb) as well as castor genome (323 Mb). Traditionally, Jatropha seed and other plant parts have been used for oil, soap and medicinal compounds (Kohli et al., 2009). *Jatropha* is popularized as unique candidate among renew-able energy sources due its peculiar features like drought tolerance (Openshaw, 2000), rapid growth, and easy propagation, higher oil content than other oil crops (Achten et al., 2008), small gestation period, wide range of environmental adaptation, and the optimum plant size and architecture make it as a sole candidate for further consideration (Sujatha et al., 2008). Its cultivation requires simple technology, and comparatively modest capital investment. The seed yield reported for *Jatropha* varies from 0.5 to 12 tons' year−1 ha−1 depending on soil, nutrient and rainfall conditions and the tree has a productive life of over 30 years (Francis et al., 2005 and Openshaw, 2000). The seeds contain 30–35% oil that can be converted into good quality biodiesel by transesterification (Foidl et al., 1996).

Despite the toxicity of the JSL seeds, edible varieties exist in Mexico (Schmook and Serralta, 1997), which is not currently being exploited. These are often consumed by the local population after cooking. A comparative analysis of edible and non-edible seed varieties revealed that edible seeds lacked phorbolesters (Makkar et al., 1998 and Makkar et al., 1998). Although oil is more valuable than meal, the seed meal is potentially a valuable commodity. The ability to use JSL meal as animal feed not only improves the economics of JSL production, but also adds its diversified applications in both fuel and feed. The true potential of *Jatropha* has, however, not yet been realized but now the conditions for its exploitation have improved consider-ably in recent years due to the increase of crude oil prices and policy incentives for the exploration of indigenous and renewable fuels. Nevertheless, several agro-technological challenges remain for the exploitation of *Jatropha* as a commercial crop. Although *Jatropha* has been scientifically investigated earlier for useful secondary metabolites, the kind of comprehensive research and development efforts necessary to generate economic viability and the critical information of its growth and yield in the different climatic and edaphic regions have only started recently. Results of such research are trickling in slowly; yet, the high market demand for biodiesel has excited in many organizations for the *Jatropha* plantations, because renewable energy is important for sustainable environmental development (Chel and Kaushik, 2011).

The success of these ventures rests on the continuous inflow of relevant information from research into practice (Francis, 2008). Based on these interesting properties, potentials and hyped claims, a lot of investors, policy makers and clean development mechanism project developers are interested in JSL to tackle the challenges of energy supply and

Green House Gas (GHG) emission reduction (Rao, 2006) also raised sustainable issues (societal and economical) for promotion of JSL in Indian scenario. The aim is to develop alternative energy options in rural areas that will help to promote sustainable livelihoods in this region. In this respect switching from fossil fuels or other GHG emitting sources to renewable sources of energy makes sense to combat with the effects climate changes, to have a quality environment around us.

The cost of bio-diesel is the most important aspect of pro-motion of *Jatropha* for bio-diesel production in the country, being eco-friendly, easy to produce raw material, easy oil extraction and transesterification. This review gives a current knowledge of JSL as multifunctional role for eco-environmental benefits and simultaneous wasteland reclamation, carbon sequestration, biodiesel production, and employment generation. Figure 1 shows the distribution of *Jatropha* in India.

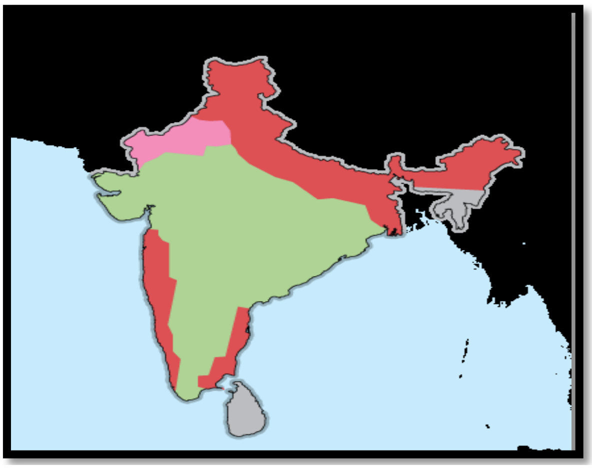

Figure- 1 Jatropha cultivation zones.

Table1. The composition and characteristics of the crude Jatropha SL (JSL) oil.

	Range	Mean	S.D.	n
Specific gravity (gcm^{-3})	0.860-0,933	0.914	0.018	13
Calorific value (MJkg^{-1})	37.83-42.05	39.63	1.52	9
Pour point (˚C)	-3			2
Cloud point (˚C)	2			1
Flash point (˚C)	210-240	235	11	7
Cetane value	38.0-51.0	46.3	6.2	4
Saponification number (mgg^{-1})	102.9-209.0	182.8	34.3	8
Viscosity at 30˚C (cSt)	37.00-54.80	46.82	7.24	7
Free fatty acids % (kg kg^{-1}*100)	0.18-3.40	2.18	1.46	4
Unsaponifiable % (kg kg^{-1}*100)	0.79-3.80	2.03	1.57	5
Iodine number (mg iodine g^{-1})	92-112	101	7	8
Acid number (mg KOH g^{-1})	0.92-6.16	3.71	2.17	4
Monoglycerides % (kg kg^{-1}*100)	Nd-1.7			1
Diglycerides% (kg kg^{-1}*100)	2.50-2.70			2
Triglycerides % (kg kg^{-1}*100)	88.20-97.30			2
Carbon residue% (kg kg^{-1}*100)	0.07-0.64	0.38	0.29	3
Sulfur content % (kg kg^{-1}*100)	0-0.13			2

S.D=standard deviation; n = number of observation used; nd = no data

JSL CHEMISTRY AND ANALYSIS

High-energy density liquid components, which can beused to make liquid fuels, are produced in plants as triglycerides, or terpenes (Asiri et al., 1996, Gubtz et al., 1999, Barnwal, 2005 Tapanes, 2008 and Connemann et al., 1994). Triglycerides, as fats andoils, are found in the plant and animal kingdom and consist of water-insoluble, hydrophobic substance that are made of one mole of glycerol and three moles of fatty acids (Connemann et al., 1994, Dorado et al., 2004, Pramanik and Tripathi, 2005, Bouaid et al., 2005, Tiwari et al., 2007, Singh et al., 2007, Franceschini and Macchietto, 2007). Typically, 1% of the vegetable oils are made up of unsaponifiable compounds (carotenoids, phospholipids, tocophenols or tocotrienols and oxidation products) (Achten et al., 2008). The composition and characteristics of the crude *Jatropha curcas* L oil are shown in Table I.

It is observed from Table I that the values of free fatty acid (FFAs), unsaponifiable, acid number and carbon residue figures show a very wide range, a fact which indicates that the oil quality is dependent on the interaction of environment and genetics. These wide ranges should be taken into consideration with regard to further processing of the oil.

It is important to point out that pure vegetable oils (VOs) cannot be used directly in diesel engines because of the high viscosity, low volatility, and engine problems including coking on the injectors, carbon deposits, oil ring sticking, and thickening of the lubricating oils 18,26. Yet, they can be used as base for liquid engine fuels in various ways, e.g. blends with other components, micro-emulsification, transesterification (TE), and hydro treating 18. Fig 2 shows the process of biodiesel production from *Jatropha* species.

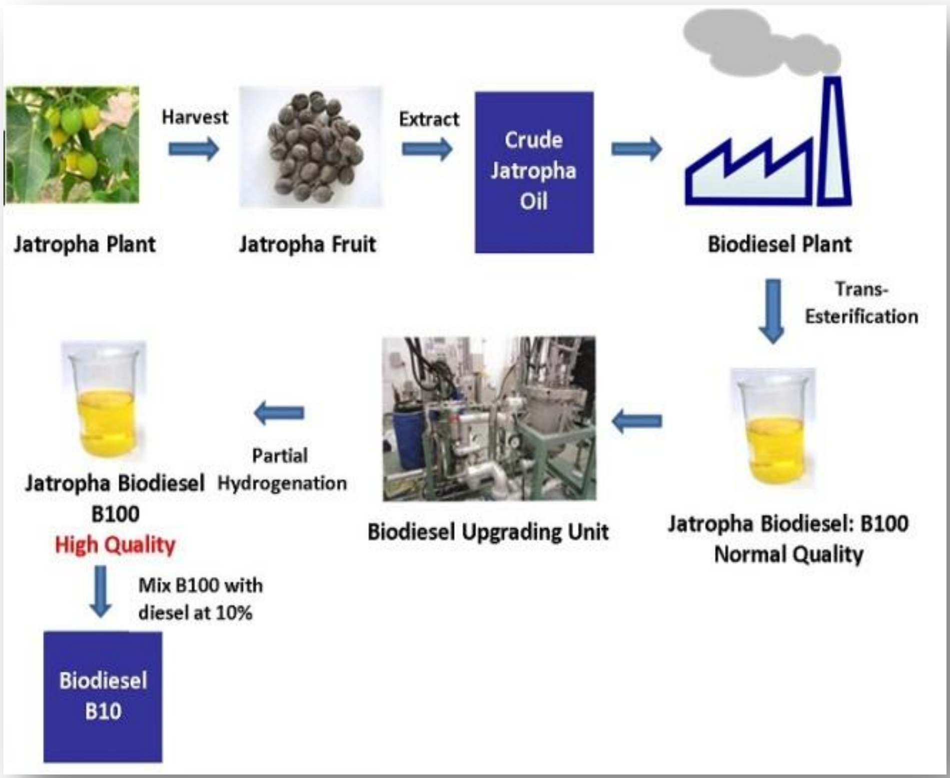

Figure 2. Process of biodiesel production from *Jatropha curcas*.

BIODIESEL PRODUCTION TECHNOLOGIES

A. Homogeneous Catalysts for the Transesterification of Vegetable Oil (Stiefel and Dassori, 2009 and Kim et al., 2004)

Transesterification Chemistry

Transesterification (called alcoholysis as vegetable oils are the reaction of the oil constituents (triglycerides) with excess methyl or ethyl alcohol, in a three-step reaction is shown by fig 3.

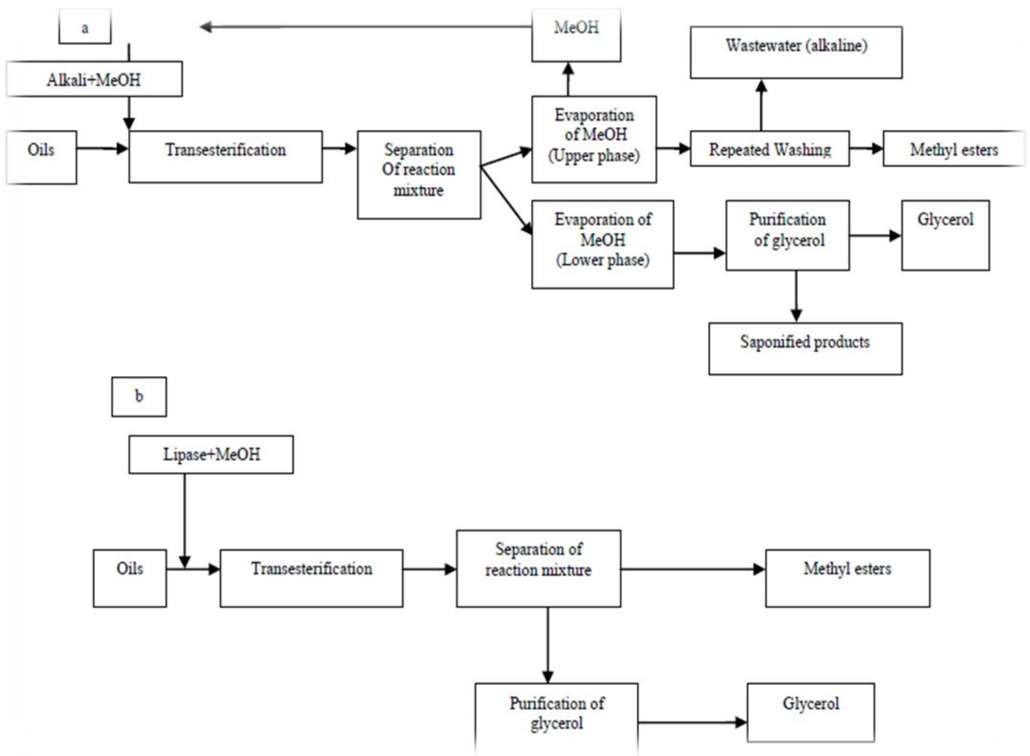

Figure 3. Flow diagram containing biodiesel process.

Figure 4. *Jatropha curcas* plant.

It has been demonstrated that the methanol - oil molar ratio, catalyst concentration, and reaction temperature are the significant parameters affecting the yield of FAME (Fatty acid methyl ester).Alkali- catalyzed TE proceeds ≈ 4000 times faster than that catalyzed by the same amount of an acidic catalyst. Methanol or ethanol is the main alcohols used for the VOs TE Potassium hydroxide is used as catalyst when ethyl alcohol is used for TE due to its higher solubility in ethanol. However, producing Fatty acid ethyl ester (FAEE) is of high interest because it yields an entirely agricultural- based fuel, besides the energy content and octane number are higher. Optimum molar ratio of alcohol/ oil is 6/1 in the case of methanol, and 12/1 for ethanol.

For TE of JC, catalyst requirement is ≈ 1 wt. % of the oil, and the reaction is conducted close to the boiling point of methanol (60-70˚C). The products of the reaction are in two phases: a glycerol –rich phase and a methyl ester- rich phase. These two phases are physically separated, and treated to produce ASTM standard Biodiesel, and pure glycerin. The optimum combination for reducing the FFAs content in *Jatropha* oil from 14% to less than 1% was found to be1.43% H_2SO_4 acid as catalyst, 0.28 V/V methanol- to-oil ratio, and 88 min. reaction time at a temp. of 60°C, as compared to a 5/1 molar ratio methanol- to- oil, and 24 min. reaction time at a temp. of 60°C for producing biodiesel, using 0.55% W/V KOH as an alkaline catalyst.

B. Heterogeneous Catalysts for the Transesterification of Vegetable Oils (Stiefel and Dassori, 2009)

Despite industrial applicability, homogeneous catalysts have their limitations: the catalyst dissolves fully in the glycerin layer, and partially in the FAME layer, which makes the product separation arduous. As a result, biodiesel should be cleaned through a slow, tedious and environmentally unfriendly water washing process to remove excess catalyst. Moreover, catalyst- contaminated glycerine is becoming a disposal problem. Another negative aspect is that the catalysts are non-reusable (Loters et al., 2005, Bokade and Yadav, 2009 and Jose et al., 1999). These problems have initiated research work and development of heterogeneous catalysts which can be easily removed from the product and recycled (Furuta et al., 2004, Loters et al., 2005, Bokade and Yadav, 2009 and Jose et al., 1999). Yet, current heterogeneous catalysts pose their own problems, namely, they are not as active as homogeneous catalysts, and they require higher reaction temps (200-250˚C) and pressure. Furthermore, it should be taken into consideration that the presence of FFAs in the feed will strongly poison solid base catalysts. In case of acidic catalysts, strong deactivation occurred when the catalyst was reused (Singh et al., 2007). Although most of the reported work in the field of TE using heterogeneous catalysts deal with research and development studies, yet, it is worth mentioning that a 160,000 T/y commercial plant, using the Hester Tip-H technology developed by the IFP, has started production since 2006. The catalyst is a mixed oxide of zinc and aluminum, the operating temperature is 200-250 ºC, and a pressure of 50 atmosphere (Bokade and Yadav, 2009). Furthermore, it should be taken into consideration that the presence of FFAs in the feed will strongly poison solid base catalysts. In case of acidic catalysts, strong deactivation occurred when the catalyst was reused (Singh et al., 2007). Although most of the reported work in the field of TE using heterogeneous catalysts deal with research and development studies, yet, it is worth mentioning that a 160,000 T/y commercial plant, using the Hester Tip-H technology developed by the IFP, has started production since 2006.

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C. Enzymatic TE of Vegetable Oils

Lipase enzymatic catalysts, can catalyze esterification and trans-esterification reactions. The advantages of lipase catalysts are their ability to catalyze both TE and E of FFAs in one step, production of glycerol side-stream with minimalwater content and little or no inorganic material, and recyclability, as could be noted from the diagrams for biodiesel production by the alkali and lipase catalysis (Fig1). It is interesting to note that *Jatropha* seeds are reported to contain lipase activity which could also catalyze TE reactions. However, enzymatic catalysts have high costs, and deactivate due to feed impurities.

D. Non-Catalytic Super Critical Vegetable Oils

With the aim of developing a novel methanolysis process for vegetable oils without using any catalyst, it has been demonstrated that preheating to a temps of 350˚C, and 100-250 atm. and treatment for 240 s in supercritical methanol are sufficient to convert vegetable oils to FAMEs with a higher yield than that obtained by alkali catalysts. Since Supercritical methanol has a hydrophobic nature with a lower dielectric constant, non-polar TGs can be well solvated with supercritical methanol to form a single phase oil/methanol mixture. Free fatty acids (FFAS) contained in the vegetable oils could also be converted efficiently to FAME in supercritical methanol, leading to increase of the total yield of FAMES. The purification of products after TE reaction is much simpler and more environmentally friendly compared with the alkali catalyzed method. However, the supercritical method requires higher temperatures and pressures, and large amounts of methanol. Fig 5 shows the schematic process of biodiesel fuel production by supercritical methanol. Reaction with SC methanol has the following advantages:

1) TGS and FFAS are reacted with equivalent rate.
2) The homogenous phase eliminates diffusive problems.
3) The process tolerates great percentages of water in thefeedstock.
4) The catalyst removal step is eliminated

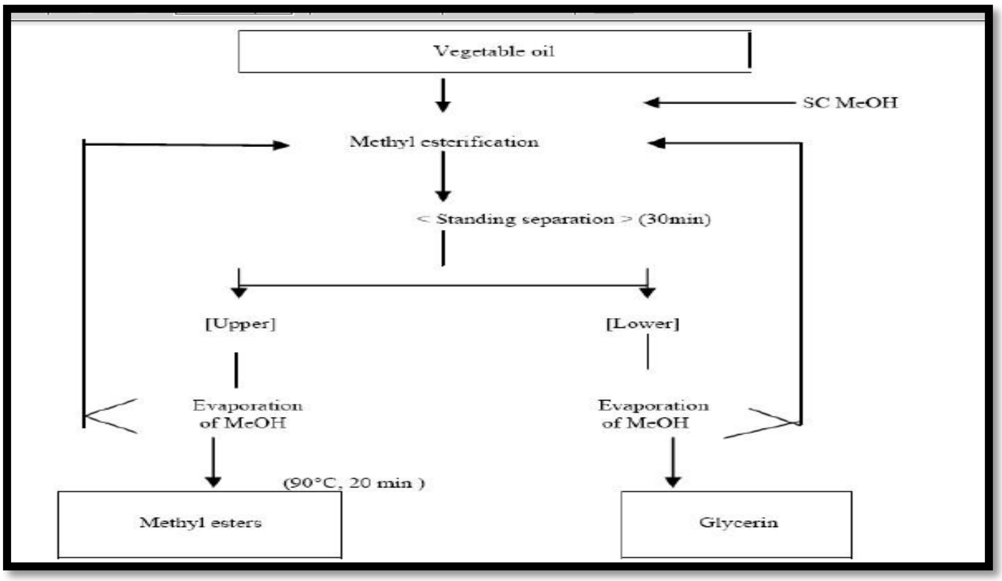

Figure 5. Schematic process of biodiesel fuel production by supercritical methanol (Singh et al., 2007).

JSL FATTY ACID METHYL ESTER EVALUATION ANDPERFORMANCE

Stability, poor low temperature properties, and a slight increase in nitrogen oxides (NOx) exhaust emissions (Thomas et al., 2000). Ethyl and isopropyl esters have improved low temperature properties without comprising octane number or oxidation stability (Thomas et al., 2000).

A. Characteristics and Composition (Achten et al., 2008)

Various specifications for FAMEs such as ASTM-D6751 and EN 14214 are presented in Table II together with JSLFAME characteristics. It is clear that JSL FAMEs comply with these specifications. Yet, there are some technical problems with biodiesel which have persisted to the present time, namely, oxidation

B. Performance

More than 100 years ago, Dr. Rudolf Diesel invented the original diesel engine and designed it to run on a host of fuels including heavy mineral oil, and vegetable oils. His first experiments were catastrophic failures, but by time he showed his engine at the World Exhibition in Paris in 1900and it was running on 100% peanut oil. Using biodiesel in a conventional diesel engine substantially reduces emissions of unburned hydrocarbons, carbon monoxide, sulphates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter. Neat biodiesel reduces CO_2 emissions by more than 75% over petroleum diesel (Thomas et al., 2000). The use of biodiesel decreases the solid carbon fraction of particulate matter since the oxygen in biodiesel enables more complete combustion to CO_2, and reduces the sulphates fraction. Emissions of nitrogen oxides (NOx) increases with the concentration of biodiesel in the fuel. Some additives have shown promise in modifying the increase (Janet et al., 2002).

CONCLUSION

In the current investigation, it has confirmed that *Jatropha* oil may be used as resource to obtain biodiesel. The experimental result shows that alkaline catalyzed transesterification is a promising area of research for the production of biodiesel in large scale.

Effects of different parameters such as temperature, time, reactant ratio and catalyst concentration on the biodiesel yield were analyzed. The best combination of the parameters was found as 6:1 molar ratio of Methanol to oil, 0.92% NaOH catalyst, 60 ^{o}C reaction temperatures and 60 minutes of reaction time the viscosity of *Jatropha* oil reduces substantially after transesterification and is comparable to diesel. Biodiesel characteristics like density, viscosity, flash point, cloud point and pour point are comparable to diesel.

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REFERENCES

Francis, G., Edinger, R. and Becker, K. (2005). A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. *Nat Resour Forum*; 29:12–24.

Openshaw, K. (2000). A review of *Jatropha* species: an oil plant of unfulfilled promise. *Biomass Bioenergy*; 19:1–15.

Carvalho, C.R., Clarindo, W.R., Praca, M.M., Araujo, F.S. and Carels, N. (2008). Genome size, base composition and karyotype of *Jatropha* species L., An important biofuel plant. *Plant Sci*; 174:613–7.

Kohli, S. A., Popluechai, Raorane, M., Syers, K.J. and O'Donnell, A.G. (2009). *Jatropha* as a novel non-edible oilseed plant for biodiesel. In: Ferry N, Gatehouse AMR, editors. Environmental impact of genetically modified novel crops. London, UK: CAB International. p. 294–322. Chapter 14.

Achten, W.M.J., Verchot, L., Franken, Y.J., Mathijs, E., Singh, V.P., Aerts, R. (2008). *Jatropha* bio-diesel production and use. *Biomass Bioenergy*; 32:1063–84.

Sujatha, M., Reddy, T.P. and Mahasi, M.J. (2008). Role of biotechnological interventions in the improvement of castor (*Ricinus communis* L.) and *Jatropha* species L. *Biotechnol Adv*; 26:424–35.

Foidl, N., Foidl, G., Sanchez, M., Mittelbach, M. and Hackel, S. (1996). *Jatropha* species L. as a source for the production of biofuel in Nicaragua. *Bioresour Technol*; 58:77–82.

Schmook, B. and Serralta-Peraza, L. (1997) J. Species: distribution and uses in the Yucatan Peninsula of Mexico. In: Jatropha. Managaua, Nicuagura/Austria: Dbv-Verlag.

Makkar, H.P.S., Aderibigbe, A.O. and Becker, K. (1998). Comparative evaluation of non-toxic and toxic varieties of Jatropha species for chemical composition, digestibility, protein degradability and toxic factors. *Food Chem*; 62:207–15.

Makkar, H.P.S., Becker, K. and Schmook, B. (1998). Edible provenances of Jatropha species from Quintana Roo state of Mexico and effect of roasting on anti nutrient and toxic factors in seeds. *Plant Foods Hum Nutr*; 52:31–6.

Chel, A. and Kaushik, G. (2011). Renewable energy for sustainable agriculture. *Agron Sustain Dev*; 31:91–118.

Francis, G. (2008). *Jatropha* species: prospects for crop management. In: Syers JK, Wood D, Thongbai P, editors. Proceedings of the international technical workshop on the "Feasibility of non-edible oil seed crops for biofuel production 2008". Chiang Rai, Thailand: Mae Fah Luang University.

Rao, V.R. (2006). The *Jatropha* hype: promise and performance. In: Singh B, Swaminathan R, Ponraj V, editors. Biodiesel conference toward energy independence—focus of *Jatropha*. India: Hyderabad. p. 16–20.

Asiri, P. K. et al (1996). "Survey of oils for use as diesel fuels," JAOCS, vol.73, no. 4, pp. 470-474.

Gübtz, G. M. et al. (1999). "Exploitation of the tropical oil seed plant Jatropha Species L," Bio resource Technology, vol. 67, pp. 73-82.

Barnwal, B. K., (2005). "Sharma Prospects of biodiesel production from vegetable oils in India," Renewable and Sustainable Energy Reviews, vol. 9, pp. 363-378, 2005.

Tapanes, N. C. O. et al. (2008). "Transesterification of *Jatropha* species oil glycerides: Theoretical and experimental studies of biodiesel reaction," Fuel, vol. 87, pp. 2286-2295, 2008.

Connemann et al. (1994). "Process for the continuous production of lower alkyl esters of higher fatty acids," U.S. Patent, Qct. 11, vol. 5, pp. 354-878.

Dorado, M. P. et al. (2004). “Optimization of alkali-catalyzed transesterification of *Brassica garinata* oil for biodiesel production,” Energy and Fuels, vol. 18, pp. 77-83.

Pramanik, T. and S. Tripathi (2005). Biodiesel: Clean fuel of the future hydrocarbon processing, February 2005, pp. 49-54.

Bouaid, A. et al. (2005). “Pilot plant studies of biodiesel production using *Brassica carinata* as row material,” Catalysis Today, vol. 106, pp.193-196.

Tiwari, A. K. et al. (2007). “Biodiesel production from *Jatropha* oil with high free fatty acid: An optimized process,” Biomass and Bioenergy, Vol.31, pp. 569-575.

Singh, A. K. et al. (2007). “Base-catalyzed fast transesterification of soybean oil using ultrasonication,” *Energy and Fuels*, Vol. 21, pp. 1161-1164.

Franceschini, G. and S. Macchietto (2007). “Validation of model for biodiesel production through model- based experiment design,” *Ind. Eng. Res*, Vol. 46, pp. 220-232.

Achten, W. M. J. et al. (2008). “*Jatropha* bio-diesel production and use,” *Biomass and Bioenergy*, Vol. 32, pp. 1063-1084.

Stiefel, S. and G. Dassori (2009). “Simulation of biodiesel production through transesterification of vegetable oils,” *Ind. Eng. Chem. Res.*, Vol. 48, pp.1068-1071.

Kim, H. J. et al. (2004). “Transesterification of vegetable oil to biodiesel using heterogeneous base catalyst,” *Catalysis Today*, Vol. 93, pp. 315-320.

Furuta, S. et al. (2004). “Biodiesel fuel production with solid super acid catalysis in fixed bed reactor under atmospheric pressure,” *Catalysis Communications*, Vol. 5, pp. 721-723.

Loters et al. (2005). “Synthesis of biodiesel via acid catalysis,” *Ind. Eng.Chem. Res*., Vol. 44, no. 14, pp. 5353-5363.

Bokade, V. V. and G. D. Yadav (2009). “Transesterification of edible on nonedible vegetable oils with alcohols over hetero-polyacids supported on acid-treated clay*,” Ind. Eng. Chem. Res*., Vol. 48, pp. 9408-9415.

José, M. et al. (1999). “Preparation and properties of biodiesels from cynara cardunculus L. oil,” *Ind. Eng. Chem. Res*., Vol. 38, no. 8, pp. 2927-2931.

Fukuda, H. et al. (2001). “Biodiesel fuel production by transesterification of oils,” Journal of *Bioscience and Bioengineering*, Vol. 92, no. 5, pp. 405-416.

Thomas, D. et al. (2000). “Effect of biodiesel, biodiesel blends, and a synthetic diesel on emissions from light heavy-duty diesel vehicles,” *Environmental Science Technology,* Vol. 34, no. 3, pp. 349-355.

Janet, M. et al. (2002). “Lubricity- enhancing properties of soy oil when used as blending stock for middle distillate fuels,” *Ind. Eng. Chem. Res*., Vol. 41, no. 5.

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