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# "Advancing the Creation of Biodiesel from Jatropha Curcas L.: A Promising Source of Renewable Energy"

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**ABSTRACT**
Biodiesel is a renewable alternative to fossil fuels that has garnered significant attention due to its environmentally friendly nature. The Jatropha plant is one of the most promising sources of biodiesel due to its high oil content, adaptability to various soil types and low water requirements. This paper reviews the production of biodiesel from the Jatropha plant, highlighting its potential as a sustainable energy source. The potential of *J. curcus* as a source for biodiesel production are highlighted here. *J. curcus* is a shrub that is known for its high oil content and adaptability to different soil types, making it a promising crop for biodiesel production. Various methods, including mechanical pressing, solvent extraction, and supercritical fluid extraction, can be used to extract oil from the plant. The extracted oil is then subjected to a transesterification reaction to produce biodiesel. Biodiesel produced from *J. curcus* has several advantages, including reduced carbon emissions, economic benefits to rural areas, and the ability to grow on marginal land. However, further research is needed to optimize the production of biodiesel from *J. curcus* and to ensure its sustainability as a renewable energy source. The Jatropha plant is a promising source of biodiesel due to its high oil content and ability to grow in arid and semiarid regions with low rainfall.
**KEYWORDS:** biodiesel, jatropha plant, transesterification, economic benefits, renewable energy source

## INTRODUCTION
Every aspect of a nation's economic development is dependent on energy. As a result, demand for energy has been steadily rising alongside population and industrialization growth. Petroleum, natural gas, and coal from fossil fuels are common energy sources. Non-renewable energy resources have been rapidly depleted as a result of this rising energy consumption. Every nation's energy security is a major concern due to the rising cost of fossil fuels and the possibility of a shortage in the future (Robles-Medina et al., 2009). Additionally, there are numerous drawbacks to using fossil fuels, such as air pollution and environmental problems. Emissions from fossil fuels are a major source of greenhouse gases that have the potential to cause global warming. Carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), hydrocarbons, particulates, and compounds that can cause cancer are all major sources of air pollutants (National Biodiesel Board, 2010; Diwani et al., 2009).
One of the most promising non-renewable energy sources of alternative fuel is biodiesel. A fuel composed of mono-alkyl esters of long-chain fatty acids derived from vegetable oil or animal fat is referred to as biodiesel (Su and Wei, 2008). Biodiesel has many advantages over conventional diesel. Biodiesel has several advantages: It helps engines reduce emissions of carbon dioxide and other pollutants; It does not require engine modification because it has similar properties to diesel fuel; It comes from renewable sources, allowing people to grow their fuel; Diesel engines perform better with biodiesel due to its high cetane number; High purity of biodiesel would eliminate the need for lubricant; Biodiesel production is more efficient than that of fossil fuels because there will be no underwater plantations, drilling, or refineries. Biodiesel would enable a region to become energy self-sufficient because it can be produced locally (Jain and Sharma, 2010a; Jayed et al., 2009; Nie et al., 2006; Robles-Medina et al., 2009; Shah et al., 2004; Su and Wei 2008; Vieira et al., 2006).
Researchers have been focusing on producing biodiesel from non-edible oils as the other oils (edible oil, vegetable oils, animal fat, and used cooking oils) have been posing numerous drawbacks. *J. curc*as (Jatropha), Pongamia pinnata (Karanja), Madhuca indica, Calophyllum inophyllum (Polanga), Hevea brasiliensis (Rubber), and others are examples of nonedible, oil-producing

plants (Pinzi et al., 2009). In terms of its economic, social, and environmental benefits, jatropha is the plant that is most advantageous for the production of biodiesel (Juan et al., 2011).

**JATROPHA PLANT AS A SOURCE OF BIODIESEL: FUEL PROPERTIES**

The Jatropha plant is a perennial shrub that belongs to the Euphorbiaceae family. It is native to Central and South America but is now grown in tropical and subtropical regions around the world. The plant can grow up to 6 meters tall and has a lifespan of up to 50 years. The Jatropha plant is well-suited for biodiesel production due to its high oil content of up to 40% and low water requirements, making it an ideal crop for arid and semi-arid regions. The oil from the Jatropha plant can be extracted using various methods, including mechanical pressing, solvent extraction, and supercritical fluid extraction. After extraction, the oil undergoes a transesterification reaction to produce biodiesel. This reaction involves the conversion of the triglycerides in the oil into methyl esters through the addition of alcohol and a catalyst. The resulting biodiesel can be used as a fuel for diesel engines or blended with conventional diesel fuel.

*J. curcas* is a drought-tolerant perennial that grows well in marginal/poor soils. It is easy to establish, grows relatively quickly, and lives by producing seeds for 50 years. The miracle plant Jatropha produces seeds with an oil content of 37%. The oil can be burned as fuel without being refined. It burns with a clear, smokeless flame and has been successfully tested as a fuel for simple diesel engines. Among the various oilseeds, J. *curcas* has proven to be more suitable for biodiesel production due to its various properties. Cultivation of jatropha is possible under stress conditions and the oil of these species with different properties is more suitable for biodiesel production. *J. Curcas* has been scientifically engineered to provide better oil yield and productivity. Jatropha oil has a higher cetane number than other oils compared to diesel (40-55) making it an ideal alternative fuel and requiring no modification to the engine (Pramanik, 2003).

| Si.No | Properties | Diesel | *J. curcas* oil |
|---|---|---|---|
| 1. | Density (gm/cc), at 30°C | 0.836-0.850 | 0.93292 |
| 2. | Kinematic viscosity (cSt), | 4-8 | 52.76 |
| 3. | Cetane no. | 40-55 | 38.00 |
| 4. | Flash point,°C | 45-60 | 210.00 |
| 5. | Heating values (MJ/kg) | 42 | 39-40 |
| 6. | Specific gravity at 15°C | 0.82-0.86 | 0.912 |

**Table 1: Fuel properties of *J. curcas* oil (Pramanik, 2003)**

**Optimization of Biodiesel Production from Jatropha Plant**

To overcome the challenges in biodiesel production from Jatropha, various approaches have been proposed. One approach is to improve the oil content and quality of Jatropha seeds through genetic modification and the selection of high-yielding cultivars. Another approach is to optimize the extraction and transesterification processes to increase the yield and quality of biodiesel produced. For example, using a combination of solvent extraction and supercritical fluid extraction has been shown to increase the yield of oil and improve the quality of biodiesel produced. Optimizing the production process can also reduce the cost of biodiesel production from Jatropha, making it more commercial (Mohammed et al., 2021).

| Factors for Optimization | Methods |
|---|---|
| Feedstock Selection | Genetic modification for higher oil content, selection of high-yielding Jatropha cultivars. |
| Extraction Method | Soxhlet extraction, ultrasound-assisted extraction, supercritical fluid extraction. |
| Transesterification catalyst | Alkaline catalysts (NaOH, KOH), acidic catalysts (H2SO4, HCl), enzymatic catalysts. |
| Reaction conditions | Optimum temperature and pressure, molar ratio of alcohol to oil, reaction time. |
| Separation and purification | Washing with water, drying, removal of excess alcohol and glycerol, neutralization, purification through distillation, crystallization, or membrane filtration. |
| Quality control | Analysis of biodiesel properties (density, viscosity, flash point, cetane number), testing for impurities and contaminants, compliance with biodiesel standards. |
| Sustainability considerations | Use of renewable energy for processing, reduction of water and chemical usage, waste management, environmental impact assessment. |

**Table 2: Optimization of Biodiesel Production from Jatropha Plant (Mohammed et al., 2021)**

**PROCESSING TECHNIQUES**

Crude oil, which includes free fatty acids, phospholipids, sterols, water, odorants, and other impurities, is produced by pressing natural vegetable oils and animal fats. Vegetable oils cannot be used as fuel in compression engines because of these components, their high viscosity, low volatility, and their polyunsaturated nature. Linoleic acid and oleic acid are the two predominant unsaturated fatty acids in jatropha seed oil, which contains about 72% of them. Jatropha oil's viscosity is significantly lower than some commonly used and evaluated oils, such as soybean cottonseed, and sunflower, indicating that it is suitable for use as diesel fuel.

These factors make *J. curcas* appropriate and advantageous for producing biodiesel. Since these vegetable oils are renewable by nature, they are a better supply for the creation of biodiesel than animal fats and used cooking oil. There are worries that biodiesel made from veggie oil will disrupt the food market, though. Because jatropha is not edible and can grow readily in harsh environments, its oil is a suitable option for biodiesel production. Furthermore, JCO's alkyl ester satisfies the biodiesel requirement in many nations.

Three stages are required to make biodiesel: acid catalyze esterification, base catalyze transesterification, and washing process (Yusoff et al., 2013).

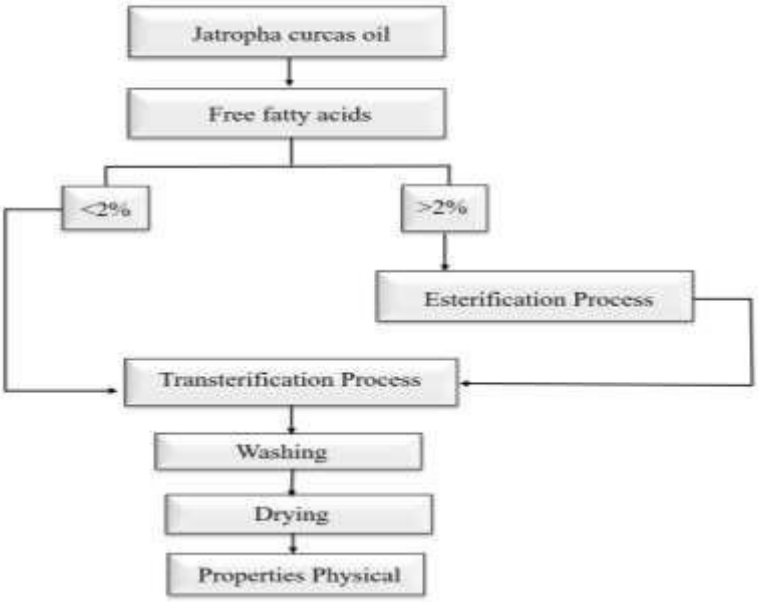


**Fig 1: Process flowchart for biodiesel (Yusoff et al., 2013)**

## ESTERIFICATION PROCESS

Purpose of the esterification process is to reduce the free fatty acid (FFA) by converting it into esters. Theoretically, esterification will also boost biodiesel yield. Methanol and sulphuric acid ($H_2SO_4$) were the chemical reactions used in this process. Based on the ratio, the alcohol and acid catalyst were used in this process. To reduce free fatty acids, the same ratio of alcohol to acid catalyst was utilized previously. The catalyst is one percent, and the ratio of methanol to oil is 16:1(Berchmans & Hirata, 2008). The esterification reaction was followed for the pre-treatment step in this study. First, the JCO was heated in the reactor with three neck flasks. After heating to the specified temperature, the 1% solution of sulphuric acid ($H_2SO_4$) in methanol was added to the reactor containing the heated JCO. Methanol was used in a 16:1 ratio with JCO (Berchmans & Hirata, 2008).

## TRANSESTERIFICATION PROCESS

The best way to make biodiesel is through alcohol transesterification of vegetable oils. There are two approaches to transesterification: a) containing a catalyst and b) omitting one. The rate and yield of biodiesel can be improved by using a variety of catalysts. Excess alcohol shifts the equilibrium to the product side, reversing the transesterification reaction (Lapuerta et al., 2009) (Chisti, 2007). Vastly different liquor can be utilized in this response, including methanol, ethanol, propanol, and butanol. Due to its low cost, popularity, and short alcohol chains, as well as its physical and chemical advantages, the application of methanol is more feasible. Vastly different liquor can be utilized in this response, including methanol, ethanol, propanol, and butanol. Due to its low cost, popularity, and short alcohol chains, as well as its physical and chemical advantages, the application of methanol is more feasible (Lapuerta et al., 2009)

To make methyl ester, ester, and alcohol are combined in transesterification. Methanol was used in this experiment due to its lower cost and ease of availability in comparison to other alcohols like ethanol and propanol (butanol). The catalyst will be sodium hydroxide (NaOH). This catalyst was chosen for its quick reaction and safety (Lapuerta et al., 2009) (Chisti, 2007).

## WASHING AND SEPARATION PROCESS

The production of biodiesel from *J. curcas* oil involves several steps, including washing and separation processes. Here is a general overview of these processes: Collection and Preparation of *J. curcas* seeds: *J. curcas* seeds are collected and cleaned to remove any foreign matter or impurities. Extraction of oil: The oil is extracted from the seeds using either mechanical or solvent extraction methods. Washing of oil: The extracted oil is washed with water to remove any impurities or residual solids. Separation of oil: The washed oil is then separated from any water or other impurities using a centrifuge or settling tank. Drying of biodiesel: The washed biodiesel is dried to remove any remaining water before it is ready for use. After the washing process to get the pure biodiesel, fatty acid methyl ester (FAME) must heat 5 hours or above at 100ºC in the oven. Overall, the washing and separation processes are crucial steps in producing high-quality biodiesel from *J. curcas* oil. These processes help to remove impurities and ensure that the final product meets the required specifications.

**PURIFICATION PROCESS**

The purification process in the production of biodiesel from Jatropha curcas involves several steps to remove impurities and contaminants.

(i) Settling and Separation: After the transesterification process, the mixture of biodiesel, glycerol, and other by-products is transferred to a settling tank. The tank allows the separation of the heavier glycerol phase from the lighter biodiesel phase based on their different densities. Gravity aids in the settling process, but sometimes a centrifuge is used to accelerate the separation. The settled glycerol is then drained off or removed using a separation device, leaving behind the biodiesel. (ii) Acid Neutralization: Jatropha curcas biodiesel is known to contain free fatty acids (FFAs), which can hinder the quality of the fuel and cause problems during storage and usage. To remove these FFAs, an acid neutralization step is employed. A small amount of acid (typically sulfuric acid) is added to the biodiesel, and the mixture is agitated. The acid reacts with the FFAs to form soaps, which can be easily separated from the biodiesel during the washing step. (iii) Washing: The acidified biodiesel is washed to remove impurities such as residual catalyst, soaps, and water-soluble contaminants. The washing process usually involves multiple stages using water or an aqueous solution. The biodiesel and washing medium are mixed together and allowed to settle. The water phase, containing the impurities, is drained off, while the biodiesel layer is retained. This washing process can be repeated several times to achieve the desired purity level.(iv) Drying: Water content in biodiesel should be minimized to prevent quality issues and promote storage stability. The washed biodiesel is typically dried using different methods. One common approach is to use heat and evaporation by passing the biodiesel through a drying column or using a heat exchanger. Alternatively, adsorbents such as anhydrous sodium sulfate or molecular sieves can be employed to absorb the remaining water molecules. The drying process helps ensure the biodiesel meets the required water content specifications. (v) Filtration: The final purification step involves filtration to remove any remaining solid impurities or particles. This process ensures the biodiesel has a clear appearance and is free from contaminants that could potentially clog fuel filters or injectors. Filtration can be performed using various types of filters, including paper filters or mesh screens, which effectively trap solid particles while allowing the biodiesel to pass through.(vi) Optional Additive Treatment: Depending on the specific requirements or market standards, additional treatments may be performed to improve the quality and properties of the biodiesel. For instance, antioxidants or stabilizers may be added to enhance the fuel's oxidative stability and prolong its shelf life. Moreover, certain additives can be incorporated to enhance cold flow properties or improve lubricity.

**JATROPHA AS AN OPTION OF TRANSPORT FUEL**

Pollutants resulting from the combustion of fossil fuels for diesel engines are one of the most significant contributors to environmental pollution. Diesel motor poisons significantly affect both the climate and human well-being. Due to several factors, including global environmental concerns, rising petroleum costs, and the anticipated depletion of fossil diesel fuel, researchers are investigating the clean combustion of diesel engines using alternative fuels. Scientists have been working worldwide for decades to discover new alternative fuels that are widely available, technically feasible, financially viable, and beneficial to the environment (Valipour, 2014).

To meet the rising energy needs of the world, alternative energy sources are required. Due to the predicted depletion of fossil fuel sources and the rising cost of such fuels, biodiesel fuels are being studied as potential diesel replacements. Among its advantages are a higher cetane index and lower carbon dioxide emissions. Biodiesel is a clean-burning, oxygenated mono-alkyl ester fuel made from natural, renewable resources like new or used vegetable oils and animal fats (Enweremadu and Mbarawa, 2009).

Biodiesel is a clean alternative fuel that emits less greenhouse gas emissions because it does not contain sulfur, aromatic hydrocarbons, metals, or leftover crude oil. Biodiesel has numerous advantages. It can be mixed with diesel fuel in any quantity. It can be used in a diesel engine without modifying it; It does not contain any toxic ingredients; and it releases fewer pollutants into the environment that are harmful (How et al., 2012; Ng and others, 2012). Biodiesel is becoming more and more popular all over the world, particularly in developing nations.

**ADVANTAGES OF JATROPHA BIODIESEL**

Compared to diesel, biodiesel is an environmentally friendly liquid fuel that does not cause any problems for the environment. Up to B20, biodiesel may not necessitate engine modifications. However, minor adjustments may be required for higher blends. Biodiesel is less expensive than diesel and can be used as "on-farm fuel" by farmers who grow seed oil crops, make biodiesel, and use it in the field. Biodiesel can improve vehicle performance because it has a cetane number of over 100, which indicates the fuel's ignition quality. Unlike diesel engines, biodiesel can be used without adding any additional lubricant due to its clarity and purity (Enweremadu and Mbarawa, 2009). Biodiesel lessens the impact that a waste product has on the environment. Biodiesel does not in any way contribute to nature's garbage because it is produced from waste products themselves. Utilized cooking oils and lards can be used to make biodiesel. Therefore, the capability to transform these substances into biodiesel is more than welcome rather than their disposal. Biodiesel uses less energy. When biodiesel production is compared to regular diesel production, the latter requires more energy to produce (How et al., 2012; Ng and others, 2012). Unlike petroleum diesel, biodiesel does not require drilling, transportation, or refinement. Biodiesel production is simpler and quicker. It is made in-house. A fuel that is produced locally will save money. The nations from which oil and petroleum diesel are sourced are not required to pay tariffs or other taxes of a similar nature. Biodiesel production is a capability of every nation (Elkelawy et al., 2019).

**STABILITY OF BIODIESEL: CHALLENGES IN BIODIESEL PRODUCTION FROM JATROPHA PLANT**

While the Jatropha plant is a promising source of biodiesel, there are several challenges in its production. One of the main challenges is the variability in the oil content and quality of Jatropha seeds due to factors such as seed origin, climatic conditions, and seed storage. This variability affects the yield and quality of biodiesel produced. It has been found that biodiesel made from vegetable oils and other raw materials is more susceptible to oxidation due to exposure to atmospheric oxygen and high temperatures, mainly due to the presence of different numbers of double bonds in the free fatty acid molecules. The chemical reactivity of fixed oils and esters can therefore be divided into oxidative and thermal instability, which can be determined by the amount and configuration of olefinic unsaturation in the fatty acid chains. Many fatty vegetable oils such as soybeans and rapeseed contain polyunsaturated fatty acids that are more prone to oxidation. This structural fact is key to understanding both oxidative and thermal instability (Koh & Mohd. Ghazi, 2011). Another challenge is the high cost of Jatropha cultivation and the need for extensive land preparation, including soil amendment and irrigation, to achieve optimal yields. The cost of biodiesel production from Jatropha is also high compared to conventional diesel fuel, which may limit its commercial viability.

## APPLICATIONS OF BIODIESEL IN COMBUSTION ENGINES

Engine performance and emissions using *J. curcas*-based biodiesel for various test conditions are summarized. Engine types, operating methods, combustion processes, and various properties of biodiesel fuels all have a significant impact on the performance, combustion, and emission characteristics of diesel engines fueled with Jatropha biodiesel. Biodiesel fuels have a higher oxygen concentration, they burn more efficiently (Elkelawy et al., 2019). To evaluate engine performance, researchers typically look at engine torque, braking power (BP), brake-specific fuel consumption (BSFC), brake-specific energy consumption (BSEC), brake thermal efficiency (BTE), and exhaust gas temperature (EGT). To study emissions, authors typically study nitrogen oxides (NOx), hydrocarbon emissions (HC), carbon dioxide (CO2), carbon monoxide (CO), and smoke opacity (SO). Some research has shown that the use of jatropha biodiesel reduces BTE (Chauhan et al., 2010; Kathirvelu et al., 2017). BP decreases as the amount of biodiesel in the fuel blend increases (Thapa et al., 2018). BTE, on the other hand, decreases when the amount of jatropha biodiesel in the fuel mix increases (Madiwale et al., 2018). Increasing the proportion of jatropha biodiesel in the diesel-biodiesel blend reduces HC emissions (Chauhan et al., 2012). In most cases, NOx emissions from jatropha biodiesel are higher than those from diesel fuel (Abed et al., 2019). Jatropha biodiesel and its blends typically reduce CO emissions by 1040% compared to full-load diesel (Huang et al., 2010; Singh A. et al., 2021). The increase in CO emissions becomes noticeable when the load percentage increases (Sundaresan et al., 2007). Smoke opacity decreases as the biodiesel content in the blend increases, but increases as the load on jatropha biodiesel and its blends increases (Chauhan et al., 2012; Pandhare and Padalkar, 2013). Engine types, operating methods, combustion processes, and various properties of biodiesel fuels all have a significant impact on the performance, combustion, and emission characteristics of diesel engines fueled with Jatropha biodiesel.

## CONCLUSION

Alternative energy sources are required to meet the rising global energy requirements. Biodiesel fuels are being viewed as potential diesel replacements due to the anticipated depletion of fossil fuel sources in the future and the rising cost of such fuels. Based on a variety of characteristics, it has been determined that among the various oil seeds, J. *curcas* is better suited for the production of biodiesel (Jain & Sharma, 2010). Under stressful conditions, Jatropha can be grown, and the oil of these species, which has a variety of characteristics, is better suited for the production of biodiesel. The scientifically developed *J. curcas* yields oil with greater productivity. The cetane number of jatropha oil is higher when compared to diesel and other oils, making it an ideal alternative fuel that does not require engine modification (Enweremadu and Mbarawa, 2009). The primary issue with biodiesel is that it oxidizes over time when exposed to the environment, resulting in an increase in fuel viscosity. Controlling the oxidation of biodiesel from edible seeds is the subject of ongoing research at both the national and international levels. However, biodiesel made from seeds that aren't edible also requires a lot of work in this area. Jatropha-based biodiesel is anticipated to be a viable long-term alternative due to the rapid depletion of fossil fuel reserves (coal, oil, and gas). If these fossil fuel resources are utilized for an extended period of time, global resources will eventually run out because they are limited. In conclusion, the Jatropha plant stands out because of the numerous ecological, energy, and financial benefits associated with its commercial use. Additionally, increasing its use is beneficial to the environment and food production (Riayatsyah et al., 2022).

## REFERENCES


1. Abed, K. A., Gad, M. S., El Morsi, A. K., Sayed, M. M., and Elyazeed, S. A. (2019). Effect of Biodiesel Fuels on Diesel Engine Emissions. *Egypt. J. Pet.* 28, 183–188. doi:10.1016/j.ejpe.2019.03.001
2. Agarwal, D., Agarwal, A.K., 2007. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl. Therm. Eng. 27, 2314–2323.
3. Berchmans, H. J., & Hirata, S. (2008). Biodiesel production from crude Jatropha curcas L. seed oil with a high content of free fatty acids. Bioresource technology, 99(6), 1716–1721.
4. Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: An overview. (2010, September 30). In *Biodiesel production from jatropha oil by catalytic and non-catalytic approaches.* doi:10.1016/j.biortech.2010.09.093
5. Chauhan, B. S., Kumar, N., and Cho, H. M. (2012). A Study on the Performance and Emission of a Diesel Engine Fueled with Jatropha Biodiesel Oil and its Blends. *Energy* 37, 616–622. doi:10.1016/j.energy.2011.10.043
6. Chauhan, B. S., Kumar, N., Du Jun, Y., and Lee, K. B. (2010). Performance and Emission Study of Preheated Jatropha Oil on Medium Capacity Diesel Engine. *Energy* 35, 2484–2492. doi:10.1016/j.energy.2010.02.043
7. Chisti, Y. (2007, May). Biodiesel from microalgae. *Biotechnology Advances, 25*(3), 294–306.
8. Diwani, G., Attia, N.K., Hawash, S.I., 2009. Development and evaluation of biodiesel fuel and byproducts from Jatropha oil. Int. J. Environ. Sci. Technol. 6, 219–224
9. Elkelawy, M., Alm-Eldin Bastawissi, H., Esmaeil, K. K., Radwan, A. M., Panchal, H., Sadasivuni, K. K., et al. (2019). Experimental Studies on the Biodiesel Production Parameters Optimization of sunflower and Soybean Oil Mixture and DI Engine Combustion, Performance, and Emission Analysis Fueled with Diesel/biodiesel Blends. *Fuel* 255, 115791. doi:10.1016/j.fuel.2019.115791.
10. Enweremadu, C. C., and Mbarawa, M. M. (2009). Technical Aspects of Production and Analysis of Biodiesel from Used Cooking Oil-A Review. *Renew. Sustainable Energ. Rev.* 13, 2205–2224. doi:10.1016/j.rser.2009.06.007
11. How, H. G., Teoh, Y. H., Masjuki, H. H., and Kalam, M. A. (2012). Impact of Coconut Oil Blends on Particulate-phase PAHs and Regulated Emissions from a Light Duty Diesel Engine. *Energy* 48, 500–509. doi:10.1016/j.energy.2012.10.009
12. Jain, S., Sharma, M.P., 2010a. Prospects of biodiesel from Jatropha in India: a review. Renew. Sust. Energ. Rev. 14, 763–771.

13. Jayed, M.H., Masjuki, H.H., Saidur, R., Kalam, M.A., Jahirul, M.I., 2009. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. Renew. Sust. Energ. Rev. 13, 2452–2462.

14. Koh, M. Y., & Mohd. Ghazi, T. I. (2011, June). A review of biodiesel production from Jatropha curcas L. oil. *Renewable and Sustainable Energy Reviews*, *15*(5), 2240–2251.

15. K Pramanik, Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine, Renewable Energy, Volume 28, Issue 2, 2003, Pages 239-248, ISSN 0960-1481,

16. Lapuerta, M., Rodríguez-Fernández, J., & de Mora, E. F. (2009, November). Correlation for the estimation of the cetane number of biodiesel fuels and implications on the iodine number. *Energy Policy*, *37*(11), 4337–4344.

17. Madiwale, S., Karthikeyan, A., and Bhojwani, V. (2018). Properties Investigation and Performance Analysis of a Diesel Engine Fuelled with Jatropha, Soybean, Palm and Cottonseed Biodiesel Using Ethanol as an Additive. *Mater. Today Proc.* 5, 657–664. doi:10.1016/j.matpr.2017.11.130

18. Mohammed, Nurudeen Ishola, et al. “Optimization of ≪ I≫ Jatropha≪/I≫ Biodiesel Production by Response Surface Methodology.” Green and Sustainable Chemistry, vol. 11, no. 01, Scientific Research Publishing, Inc., 2021, pp. 23–37.

19. National Biodiesel Board, 2010. Biodiesel Emissions. Retrieved from: https://cleanfuels.org

20. Neupane, D., Bhattarai, D., Ahmed, Z., Das, B., Pandey, S., Solomon, J. K. Q., Qin, R., & Adhikari, P. (2021, September 23). Growing Jatropha (Jatropha curcas L.) as a Potential Second-Generation Biodiesel Feedstock. Inventions, 6(4), 60.

21. Nie, K., Xie, F., Wang, F., Tan, T., 2006. Lipase catalyzed methanolysis to produce biodiesel: optimization of biodiesel production. J. Mol. Catal. B: Enzyme 43, 142–147.

22. Pinzi, S., Garcia, I.L., Lopez-Gimenez, F.J., Luque de Castro, M.D., Dorado, G., Dorado, M.P., 2009. The ideal vegetable oil-based biodiesel composition: a review of social, economical and technical impacts. Energy Fuels 23, 2325–2341.

23. *Prospects of biodiesel from Jatropha in India: A review*. (2009, October 30). Prospects of Biodiesel from Jatropha in India: A Review. doi:10.1016/j.rser.2009.10.005

24. Riayatsyah, T. M. I., Sebayang, A. H., Silitonga, A. S., Padli, Y., Fattah, I. M. R., Kusumo, F., Ong, H. C., & Mahlia, T. M. I. (2022, January 14). Current Progress of Jatropha Curcas Commoditisation as Biodiesel Feedstock: A Comprehensive Review. *Frontiers in Energy Research*, *9*.

25. Robles-Medina, A., Gonzales-Moreno, P.A., Esteban-Cerdan, L., Molina-Grima, E., 2009. Biocatalysis: towards ever greener biodiesel production. Biotechnol. Adv. 27, 398–408

26. Sahoo, P. K., Das, L. M., Babu, M. K. G., Arora, P., Singh, V. P., Kumar, N. R., et al. (2009). Comparative Evaluation of Performance and Emission Characteristics of Jatropha, Karanja and Polanga Based Biodiesel as Fuel in a Tractor Engine. *Fuel* 88, 1698–1707. doi:10.1016/j.fuel.2009.02.015

27. Shah, S., Gupta, M.N., 2007. Lipase-catalyzed preparation of biodiesel from Jatropha oil in a solvent-free system. Process Biochem. 42, 409–414.

28. Singh, A., Sinha, S., Choudhary, A. K., Sharma, D., Panchal, H., and Sadasivuni, K. K. (2021a). An Experimental Investigation of Emission Performance of Heterogenous Catalyst Jatropha Biodiesel Using RSM. *Case Stud. Therm. Eng.* 25, 100876. doi:10.1016/j.csite.2021.100876.

29. Sundaresan, M., Chandrasekaran, S., and Porai, P. T. (2007). *Analysis of Combustion, Performance and Emission Characteristics of Blends of Methyl Esters of Jatropha Oil (MEJ) in DI Diesel Engine*. Society of Automotive Engineers of Japan.Sundaresan, M., Chandrasekaran, S., and Porai, P. T. (2007). *Analysis of Combustion, Performance and Emission Characteristics of Blends of Methyl Esters of Jatropha Oil (MEJ) in DI Diesel Engine*. Society of Automotive Engineers of Japan.

30. Thapa, S., Indrawan, N., and Bhoi, P. R. (2018). An Overview on Fuel Properties and Prospects of Jatropha Biodiesel as Fuel for Engines. *Environ. Technology Innovation* 9, 210–219.
doi:10.1016/j.eti.2017.12.003

31. Valipour, A. (2014). *A Review on Combustion, Performance and Emission Characteristics of Liquid Alternative Fuels for Diesel Engine*. Oxford: Oxford University Press.

32. Vieira, A.P.A., de Silva, M.A.P., Langone, M.A.P., 2006. Biodiesel production via esterification reactions catalyzed by lipase. Latin Am. Appl. Res. 36, 283–288

33. Yusoff, N. R. B. M., Hasan, S. B. H., & Abdullah, N. H. B. (2013). Process to Produce Biodiesel Using Jatropha Curcas Oil (JCO). *International Journal of Materials Science and Engineering*, 100–103.