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Current Progress of *Jatropha Curcas* Commoditisation as Biodiesel Feedstock: A Comprehensive Review

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This article looks at the national and global actors, social networks, and narratives that have influenced *Jatropha's* worldwide acceptability as a biofuel crop. *Jatropha Curcas* is a genus of around 175 succulent shrubs and trees in the *Euphorbiaceae* family (some of which are deciduous, such as *Jatropha Curcas* L.). It's a drought-tolerant perennial that thrives in poor or marginal soil and produces a large amount of oil per hectare. It is easy to grow, has a fast growth rate, and can generate seeds for up to 50 years. *Jatropha Curcas* has been developed as a unique and promising tropical plant for augmenting renewable energy sources due to its various benefits. It is deserving of being recognised as the only competitor in terms of concrete and intangible environmental advantages. *Jatropha Curcas* is a low-cost biodiesel feedstock with good fuel properties and more oil than other species. It is a non-edible oilseed feedstock. Thus it will have no impact on food prices or the food vs fuel debate. *Jatropha Curcas* emits fewer pollutants than diesel and may be used in diesel engines with equivalent performance. *Jatropha Curcas* also makes a substantial contribution to the betterment of rural life. The plant may also provide up to 40% oil yield per seed based on weight. This study looks at the features characteristics of *Jatropha Curcas* as biodiesel feedstock and performance, and emissions of internal combustion engine that operates on this biodiesel fuel.

Keywords: Jatropha biodiesel, biodiesel properties, engine performance, engine emission, economic viability

INTRODUCTION

One of the most major sources of pollution in the environment is pollutants created by the burning of fossil diesel fuel. Diesel engine pollutants have a substantial impact on both the environment and human health. Researchers are looking into the clean combustion of diesel engines using other fuel sources due to a number of factors, including worldwide environmental concerns, growing petroleum costs, and the expected depletion of fossil diesel fuel. For decades, scientists have been working throughout the world to discover new alternative fuels that are widely available, technically feasible, economically viable, and environmentally beneficial (Valipour, 2014).

Alternative energy sources are needed to address the world's growing energy demands. Biodiesel fuels are being researched as a possible replacement for diesel due to the predicted future depletion of fossil fuel sources and the present rising cost of such fuels. It has a higher cetane index and emits less carbon dioxide emissions, among other advantages. Biodiesel is a clean-burning, oxygenated mono-alkyl ester fuel manufactured from natural, renewable sources like new or used vegetable oils and animal fats (Enweremadu and Mbarawa, 2009). Italy and the United States both saw significant increases in output (where production more than tripled). Thanks to new laws, biodiesel has grown its acceptance and market share in Europe (Lieberz, 2021). In Asia, Singapore, Indonesia, Malaysia and China, as well as Latin America such as in *Argentina* and Brazil, biodiesel production was quickly rising. Indonesia expects to grow biodiesel production by 23% by 2030, while biodiesel usage is expected to rise by 7% over the next decade. (Kondalamahanty, 2021). In Asia as well as Latin America, biodiesel output was quickly increasing (*Argentina* and Brazil) (Agarwal, 2007).

Energy supply and security have been a critical concern throughout the globe in the last decade. The combustion of liquid fuels produces energy, which enables a country's economic development and prosperity. Greenhouse gases and other forms of air pollutants are emitted by fossil fuels, which negatively influence the environment. It was also noted that biodiesel is becoming more widely accessible for the transportation sector by mixing with traditional diesel fuel (Sarin et al., 2007). Growing environmental concerns, dwindling petroleum reserves, and our country's agriculture-based economy are all driving reasons behind the promotion of biodiesel to be sustainable transportation fuel.

Biodiesel is a sustainable liquid bioenergy resource that might be used to replace diesel fuel. It has the potential to reduce pollutant emissions and may be used without modification in compression ignition engines. As an alternative fuel, biodiesel possesses qualities that are comparable to diesel fuel. Transesterification is the process of turning large, branching triglycerides into smaller, straight-chain methyl esters in the presence of a solvent, employing an alkali, acid, or enzyme as a catalyst (Fattah et al., 2020). The transesterification process aids in the reduction of oil viscosity. In the presence of homogeneous catalysts such as sodium hydroxide (NaOH), potassium hydroxide (KOH), and sulphuric acid, the method works effectively (Demirbaş, 2002; Salaheldeen et al., 2021). Methanol and ethanol are the most often used solvents, with methanol being favoured due to their inexpensive cost and physical and chemical properties. They efficiently break down sodium hydroxide in these alcohols and react swiftly with triglycerides. Transesterification requires a 3:1 stoichiometric molar ratio of alcohol to triglycerides. To push the equilibrium to a maximum ester yield, the ratio must be greater in reality (Ramesh et al., 2006; Singh and Padhi, 2009; Manik and Prabu, 2013).

Because it contains no sulphur, aromatic hydrocarbons, metals, or crude oil leftovers, biodiesel is an alternative and clean fuel that emits less greenhouse gas emissions. It has the following key benefits: 1) it may be combined with diesel fuel in any quantity, 2) it can be used in a diesel engine without modification, 3) it contains no toxic ingredients, and 4) it emits less harmful pollutants into the environment (How et al., 2012; Ng et al., 2012). Biodiesel is increasing in popularity across the globe, particularly in underdeveloped nations. The first generation of biodiesel feedstocks is edible oils. Edible oils have been used to make biodiesel in the United States and Europe because they are readily accessible, have a high biodiesel production rate, and are simple to process owing to their low free fatty acid content. However, as seen in many countries, particularly in densely populated countries such as China, India, and Indonesia, their use has raised concerns such as food vs fuel concerns, environmental concerns such as the destruction of vital soil resources, deforestation, and the use of much of the available arable land (Mahapatra and Mitchell, 1999; Nurfatriani et al., 2019; Taheripour et al., 2019). All of these problems impeded the economic feasibility of producing biodiesel from food oils. The cost of feedstock is often assumed to contribute to 75% of the entire cost of biodiesel (soyabean oil, for instance) (Mizik and Gyarmati, 2021). Exploration of innovative low-cost agricultural non-edible crops and the use of by-products in biodiesel production might significantly reduce biodiesel costs, especially in developing countries where edible oils are prohibitively costly (Wang and Ding, 2012; Silitonga et al., 2019; Ambat et al., 2020; Ong et al., 2021).

The first generation biofuel is unsustainable since it competes with edible vegetable oils for food and biodiesel production (Bhatia et al., 2021). Consequently, much effort is being invested into developing biodiesels from non-edible vegetable oils such as *Jatropha Curcas*. (Takase et al., 2015), *Madhuca Indica* (Saravanan et al., 2010), *Calophyllum Inophyllum* (Azad et al., 2016; Milano et al., 2018), *Ceiba Pentandra* (Putri et al., 2012; Khan et al., 2015), *Sapium Sebiferum* (Wang et al., 2011), *Euphorbia Lathyris* (Wang et al., 2011; Zapata et al., 2012), *Reutealis Trisperma* (Kusmiyati et al., 2019), and *Pongamia Pinnata oils* (Sharma et al., 2009; Khayoon et al., 2012). Second-generation non-edible feedstocks may assist with food security while also lowering manufacturing costs dramatically. Because non-edible oil has a high percentage of free fatty acids, the biodiesel produced is viscous. Other oil sources must be investigated in order to make biodiesel production more feasible.

The use of *Jatropha Curcas* as a biodiesel feedstock has exploded in popularity in recent years. It is a tropical plant that may be grown as a commercial crop or as a hedge to protect fields from grazing animals and prevent erosion in low to high rainfall areas (Kumar and Sharma, 2008). This crop's oil can readily be transformed into a liquid biofuel that fulfils American and European requirements for biofuel (Koh and Mohd Ghazi, 2011; Teo et al., 2019). In addition, the press cake may also be used as a fertiliser, and organic waste materials can be digested to produce biogas, the bulk of which is methane (Staubmann et al., 1997; Sharma et al., 2016; Siddiki et al., 2021). The plant itself is said to be capable of preventing and controlling soil erosion, as well as acting as a living barrier and reclaiming wasteland.

A recent review by Che Hamzah et al. (Che Hamzah et al., 2020) highlights the potential of *Jatropha Curcas* as an environmentally benign biodiesel feedstock for boosting Malaysia's socio-economic growth and meeting the country's rapidly growing energy demands. Singh et al. (Singh D. et al.,

FIGURE 1 | *Jatropha Curcas L* plants.

2021) reviewed the physicochemical properties, techniques of extracting oil, production of biodiesel, as well as diesel performance and emission characteristics of biodiesel from *Jatropha Curcas*. However, their study is non-exhaustive, and a comparative analysis of extraction is missing. In another review by Meher et al. (Meher et al., 2013), authors pointed out that tropical and sub-tropical nations have started growing *Jatropha curcas* to make biodiesel. They suggested methane synthesis from the de-oiled cake, fuel briquette manufacturing from the husk and pyrolysis of *Jatropha Curcas* biomass to bio-oil with physicochemical qualities equivalent to crude petroleum as additional viable biofuel products from *Jatropha Curcas* growth. Several authors have also discussed performance and emission characteristics; however, those are outdated. Our present review addresses the botanical description of *Jatropha Curcas* and oil extraction techniques used by different researchers and oil and biodiesel physicochemical properties to date. Furthermore, the current status of performance and emission research employing *Jatropha Curcas* biodiesel and its blends is highlighted. Finally economic viability studies along with future research directions are also discussed.

BOTANICAL DESCRIPTION OF JATROPHA CURCAS

Jatropha Curcas is a drought-resistant shrub or tree that grows wild or in semi-cultivated environments. (Kumar and Sharma, 2008). Depending on soil quality and rainfall, the oil from *Jatropha curcas* nuts and seeds may be obtained after 2–5 years after cultivation. *Jatropha Curcas* nuts or seeds are produced in quantities ranging from 0.5 to 12 tonnes per year per hectare. *Jatropha Curcas* farming is effective in the tropics, where annual rainfall ranges from 250 to 3,000 mm (Foidl et al., 1996). The genus Jatropha Curcas belongs to the Euphorbiaceae family's *Jatropheae* tribe, and there are roughly 170 species recognised currently (Carels, 2009). The genus Jatropha gets its name from the Greek words "Jatros," which means "doctor," and "trophy," which means "food," and references to the plant's past medicinal uses (Kumar and Sharma, 2008). *Jatropha Curcas* is a dense shrub or small tree that may reach a height of 3–5 m (**Figure 1**). Under ideal circumstances, it may reach a height of 10 m. It has 2n = 22 chromosomes and is a diploid species (Carels, 2009).

FIGURE 2 | *Jatropha Curcas L* flowers (Perumal and Sanmugam, 2015).

Despite having a native range that spans South and Central America, South-East Asia, Africa, and India the plant now has a pantropical distribution with distinct *Jatropha Curcas* seed provenances (Garnayak et al., 2008; Kumar and Sharma, 2011; Moser, 2011). *Jatropha Curcas* may thrive in a variety of rainfall conditions, from 250 to over 1,200 mm per year (Divakara et al., 2010). This plant can tolerate temperatures between 20 and 26°C, as well as rich soil, proper drainage, and pH values between 5.0 and 6.5 (Katwal and Soni, 2003). This plant requires well-drained, well-aerated soils and thrives in low-nutrient, marginal soils, shedding its leaves during the dry season (Openshaw, 2000). Plantation areas of 2 m × 2 m, 2.5 m × 2.5 m, and 3 m × 3 m, according to Heller, are adequate and generate higher fruit harvests (Heller, 1996). The second year of operation begins to produce fruit, and by the fourth or fifth year, the economic output has stabilised.

In Mexico, there are two sorts of genotypes: hazardous and non-toxic (Becker and Makkar, 1998). It's possible that the plant will survive for up to 50 years (Achten et al., 2010). It's a deciduous plant with a morphological discontinuity and an articulated growth habit. A primary taproot and four shallow lateral roots make up the root system (Abdelgadir and Van Staden, 2013). Smooth greenish-bronze bark and transparent latex cover the glabrous branches. Smooth, 5-lobed, heart-shaped leaves, ten to 15 cm long, dark green, cordate or round, acute at the apex, cordate at the base, alternating, and dropping once a year (Nayak and Patel, 2010; Kamal et al., 2011). The flowers are borne in axillary clusters on a 3–5 cm tall stem with whole, lanceolate, or linear bracts that are highly pubescent and yellowish-green, and enormous glandular discs on the

FIGURE 3 | *Jatropha Curcas* plant with fruit (Evangelista and Cermak, 2007).

FIGURE 4 | *Jatropha Curcas* seeds with shells (Rao and Rao, 2013).

blooms (**Figure 2**) (Perumal and Sanmugam, 2015). 5 ovate-elliptic sepals, less than 4 mm long, 5 oblong-obovate petals, 6–7 mm long, densely hairy inside, and eight stamens make up the male flower. Female flowers are 4 mm long, with loose oblong petals and bigger sepals (Raju and Ezradanam, 2002; Abdelgadir et al., 2009).

Jatropha Curcas oil production is expected to reach 1,590 kg/ha (Vyas and Singh, 2007; Gui et al., 2008; Janaun and Ellis, 2010). Fruits are trilobite ovoid capsules with three cells and a length of 23–30 mm by a width of 28 mm. The seeds of *Jatropha Curcas* have a thin shell and an oblong shape with a dark back colour (Dehgan, 2012). The mature *Jatropha Curcas* seeds are 212 cm in length and may easily be cracked to extract the oil. Toxins such as phorbol esters, curcin, trypsin inhibitors, lectins, and phytates are present in such high amounts in most provenances' blackish seeds (**Figure 3**, **Figure 4**, **Figure 5**) that the seeds, oil, and seed cake are not for human consumption without detoxification (Raju and Ezradanam, 2002; Kumar and Sharma, 2011).

FIGURE 5 | *Jatropha Curcas* seeds (Rao and Rao, 2013).

Plants of substantial economic importance in this family include:

(i) Roots: *Manihot Esculenta* (cassava)
(ii) Rubber: *Hevea Brasiliensis*
(iii) Nuts: *Caryodendron Orinocense* (tacay nut)
(iv) Vegetables: *Sauropus Androgynous* (katuk)
(v) Oils: *Ricinus Communis Linn* (castor bean); *Aleurites* spp. (tung trees)
(vi) *Sapium Sebiferum* (Chinese tallow tree)
(vii) Physic nut. Hydrocarbon: *Euphorbia* spp.
(viii) Medical: *Croton* spp.; *Jatropha* spp.

JATR*OPHA* OIL EXTRACTION METHODS

Jatropha Curcas oil is stored in the fruit as triacylglycerol (TAG); to liberate these lipids, the cell wall must be weakened or disrupted. Lipid recovery from various organic sources may be accomplished using a variety of lipid extraction techniques. The type and oil content of lipid components varies. Many approaches are being used in order to improve the process by extracting the highest amount of oil from the *Jatropha Curcas* seed at the lowest possible cost (Mariana et al.). Mechanical extraction (cold press technique and expeller-pressed method) and solvent-based extraction were utilised in many developing nations to extract the oil content from the seeds (Soxhlet extraction method). Due to technological improvements in recent years, a few new technologies in oil extraction have been established, including supercritical fluid extraction, ultrasound-assisted extraction, and microwave-assisted extraction. Oil extraction techniques are intended to deliver high extraction yields and create high-value meals by obtaining high-quality oil with minimum unwanted components. In the next part, the extraction process and its benefits and drawbacks will be examined in depth. The

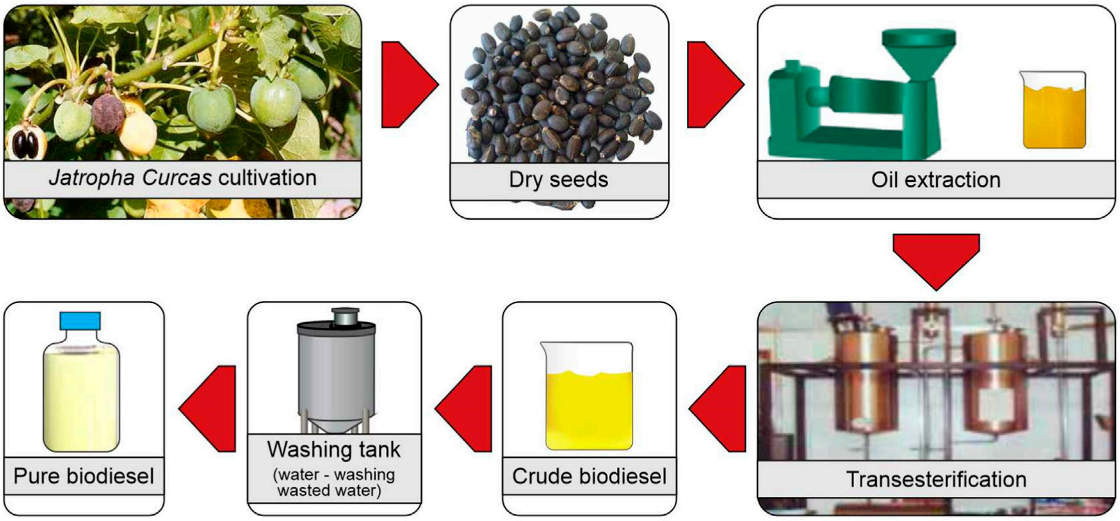

FIGURE 6 | *Jatropha Curcas* biodiesel production processes.

Jatropha Curcas biodiesel production processes is presented in **Figure 6**.

Mechanical Extraction

Mechanical pressing is a conventional oil recovery technology, and it has the lowest rate of oil recovery and is typically favoured by small businesses since it is less costly and safer than solvent extraction and requires less maintenance. **Figure 7** shows a schematic representation of a screw press machine. A helical body (worm) that spins in a tight area creates the pressing force in the mechanical pressing technique, which may be operated by either hydraulic presses or screw presses (press chamber). The hydraulic presses were replaced with continuous screw presses, which required less labour. A vertical feeder and a horizontal screw with increasing body diameter progress along the length of the press to put pressure on the oilseeds. The barrel of the screw has slots along the length of it, allowing growing internal pressure to first release air and then drain the oil through the barrel. At the end of the screw, the de-oiled cake is discharged, and the *Jatropha Curcas* oil is collected in a trough underneath the screw (Romanić, 2020). The screw press's key benefit is that it can handle enormous amounts of *Jatropha Curcas* seed with little effort, and continuously oil extraction may be done. A screw press is a machine that extracts oil by pressing seeds and nuts through a chamber with high friction and pressure. There is no additional heat added to the process, but the seeds are squeezed using friction, which generates heat between 60 and 100°C (Ionescu et al., 2014). The oil will be extracted once the seeds have been crushed. The seeds will stay in the press to form a hard "brick" that may be used as animal feed. The cold-pressed technique involves pressing the seed using an oilseed press to generate cold-pressed oil with less heat utilised or created during the process. To get the oil, the seed was put in the press and crushed by the machine. In comparison to an expeller press, the procedure may

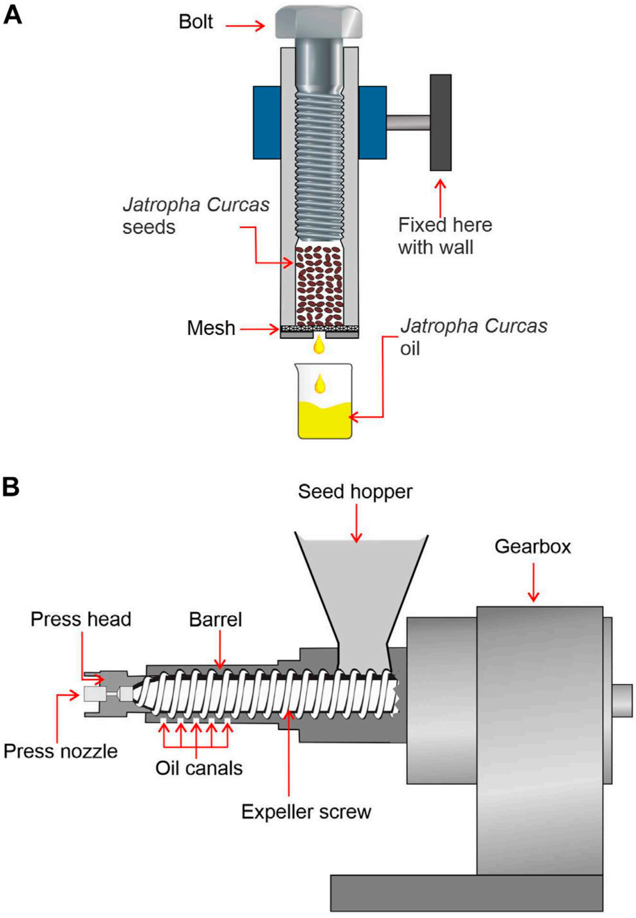

FIGURE 7 | Schematic diagram of **(A)** screw press design and **(B)** cold press oil extraction setup.

be carried out at a significantly lower temperature (50°C) (Saleem and Ahmad, 2018). Prior to the pressing process, the oilseed materials are subjected to various pre-treatments such as washing, conditioning, heating, flaking, and dehulling in order to maximise the volume and quality of oil recovered from the raw material. In the past, significant attempts were made to increase the oil extraction efficiency of screw presses. As a result, the majority of researches concentrated on improving pressing process factors such as applied pressure, pressing temperature, and moisture conditioning of the supplied sample (Ofori-Boateng et al., 2012; Subroto et al., 2015).

Other advancements to oil screw presses were the design of the machines and the materials used in their manufacture. For *Jatropha Curcas*, Chapuis et al. (Chapuis et al., 2014) conducted pilot-scale research to determine the effects of seed pre-treatment (whole, crushed, and deshelled seeds), as well as screw press operating settings (shaft rotating speed and press cake output section). According to their findings, seed preparation affects the quality and efficiency of oil extraction. The intact seed is found to have high reproductivity, but crushed seeds and deshelled seeds created unstable pressing conditions (Chapuis et al., 2014). Yate et al. (Yate et al., 2020) performed research on the mechanical extraction of *Jatropha Curcas* using a screw press type expeller. Their research looked at the oil yield under various operating settings, including changing the extraction temperature, screw rotating speed, and diameter of the nozzle at the end of the press. With the maximum examined temperature (90°C), the nozzle diameter is 11 mm, and the rotating speed is 40 rpm, the highest yield was achieved (Yate et al., 2020). This mechanical screw oil extraction press may also be utilised for other feedstocks like *Calophyllum Inophyllum*, according to Bhuiya et al. (Bhuiya et al., 2020), who conducted their research to see how processing parameters affect extraction output. With a moisture percentage of 14.4%, the kernels were able to provide roughly 78% of oil production. Mechanical screw presses are suitable for higher oil yield feedstocks since roughly 8–14% of the oil remaining in the cake and residual material. This approach is not ideal for low oil yield feedstock; instead, solvent extraction would be more appropriate.

Solvent-Based Extraction (Soxhlet Extraction Method)

Leaching is a solvent-based extraction method that involves extracting the soluble fraction (solute or leachate) from *Jatropha Curcas* seeds into a liquid solvent (Bhuiya et al., 2020). Chemical extraction has grown popular in the oil extraction business because of the high percentage of oil output and the expectation of producing high-quality oil. Due to their polar nature, different solvents may give varied oil yields when using the solvent extraction process. Oil extraction solvents such as hexane, propane, ethane, tetrahydrofuran (THF), ethanol, dichloromethane, methanol, and the methanol-water binary system were all widely employed (Haile et al., 2019; Zhang et al., 2019; Alrashidi et al., 2020). Even if there is great purity and high oil production by utilising solvent, there is still energy squandered throughout the lengthy extraction process. An experiment used Soxhlet extraction to do a Response surface methodology optimisation analysis of crude oil. The solvent to seed ratio, reaction temperature, and extraction duration were the analytical parameters. The extraction was carried out using n-Hexane as the solvent, with solid-to-solvent ratios of 3:1, 5: 1, and 7:1 (v/w) and three distinct extraction times of 4, 5, and 6 h (hrs). The reaction temperature varies between 60 and 70 C (Jose et al., 2011). Another study used a solvent extraction approach on *Calophyllum Inophyllum* feedstock and found that extraction using solvent (hexane) yielded the best yield of 86.4%, outperforming mechanical screw presses (Bhuiya et al., 2020). Alrashidi et al. (Alrashidi et al., 2020) tested the Soxhlet extraction technique for Nigella sativa L seed using several solvents. The results demonstrate that employing ethanol as a solvent yields the maximum oil yield (40.2%), whereas the methanol-water combination yields the lowest oil yield (28.3%). Rajeshwaran et al. (Rajeshwaran et al., 2020) used polar and non-polar solvents to extract oil from Prosopis Julifera feedstock for 3–8 h. They investigated the solid-to-solvent ratio, reaction time, and reaction temperature and reported that a solid-to-solvent ratio of 1: 9 (w/v) and a

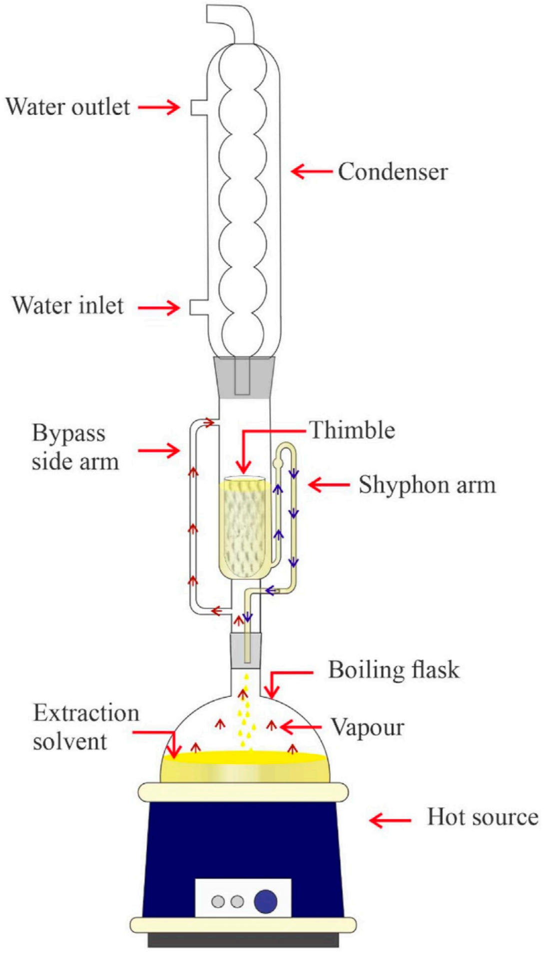

FIGURE 8 | Schematic diagram of Soxhlet extractor.

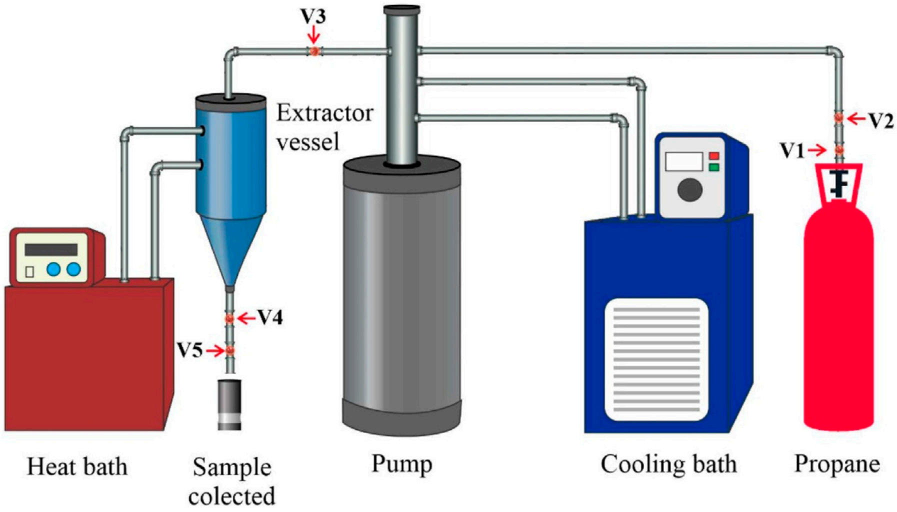

FIGURE 9 | The compressed propane system setup. Ball valves V1 and V2; needle valve V3; blockage valve V4; needle valve V5.

reaction temperature of 60 C for 9 h yielded an optimum yield of 37%. Haile et al. (Haile et al., 2019) reported that they investigated the oil extraction yield on *Moringa Stenopeta* seed collected from various locations using hexane and petroleum ether. The results show that petroleum ether is much more suitable for extracting these oils, producing 35.3–44.3% oil yield, whereas hexane produced 34.8–42.3% oil yield. Solvent extraction is a significantly more effective way of recovering oil from oilseeds than mechanical extraction since it involves dissolving oil by contacting oilseeds with a liquid solvent. The oilseed preparation, temperature, mode of operation, and equipment design all affect oil recovery efficiency. The oil and solvent combination separation is difficult with this approach, making it more appropriate for a small-scale manufacturing plant. A schematic diagram of the Soxhlet extractor is presented in **Figure 8**.

Supercritical Fluid Extraction

The supercritical fluid extraction (SCFE) method was offered as an alternative to traditional oil and oilseed processing. The essential oil sector is the most common use of this procedure. Solvents employed include ethanol, isopropyl alcohol, acetone, iso-hexane, n-hexane, propane, and other supercritical fluids, comparable to those used in the Soxhlet extraction procedure. Supercritical extraction with carbon dioxide (SC-CO_2) is a method that uses carbon dioxide as a solvent above its critical pressure and temperature. It is suggested for edible applications in the food industry (Xiong and Chen, 2020). The CO_2 used as a solvent in the supercritical fluid extraction procedure is readily removed from the *Jatropha Curcas* oil. After the oil has been extracted, the pressure in the system will be released, the CO_2 will return to the gas phase, and the oil will be precipitated from the CO_2-*Jatropha Curcas* oil combination. This eliminates the need for manual separation; nonetheless, whether CO_2 is emitted or recycled is dependent on the SCFE's design. Other solvents, such as ethanol, hexane, and others, are more difficult to separate, and the finished product is usually not suitable for culinary use but is suitable for other industries. The yield, fatty acid profile, and bioactive components of Pachira Aquatica feedstock are studied in relation to the kind of pressurised fluid used and the extraction process parameters. When n-propane was used instead of CO_2 as a co-solvent, greater oil yields were obtained. Although the yield achieved with propane extraction was lower than that obtained with Soxhlet extraction, the processing time was significantly reduced (30 min vs 16 h) (De Lara Lopes et al., 2020; Fetzer et al., 2021). Another study found that extracting spent coffee ground oil using high-pressure CO_2 and ethanol as the solvent raised the extraction yield to 16% with the working parameter of ethanol and spent coffee ground ratio: 2:1, the temperature of 80°C, 20 MPa, and extraction period of 25 min (Haile et al., 2019). Coffee oil may also be extracted from wasted coffee grounds using Norflurane as a solvent at pressures ranging from 5 to 11 bar. For 75–285 min of extraction, the oil recovery efficiency is around 92% (Cante et al., 2020). Cumaru seed oil extractions utilising propane at subcritical temperatures were carried out using a piece of improvised laboratory-scale equipment, as shown in **Figure 9** (Fetzer et al., 2020). Temperature (20, 40, 60°C), pressure (2, 6, 10 MPa), and average particle size (2, 1.7, 1.0, 0.5 mm) of Cumaru seed were all altered in the study, and the findings revealed that 98% of the total oil contained in the seeds could be extracted at 60°C, 10 MPa, and 0.5 mm. According to the research, compressed propane supplied much more unsaturated fatty acids than Soxhlet extraction using n-hexane due to the fatty acid profile (Fetzer et al., 2020).

Ultrasound-Assisted Extraction

Ultrasound-assisted extraction (UAE) is a technique for extracting plant components that might possibly be used to extract *Jatropha Curcas* oil. In comparison to previous methods, this technique allows for the extraction of natural substances in shorter timeframes, with greater reproducibility, less solvent consumption, and easier procedures. The effect of cavitation, which causes microbubbles to implode and plant

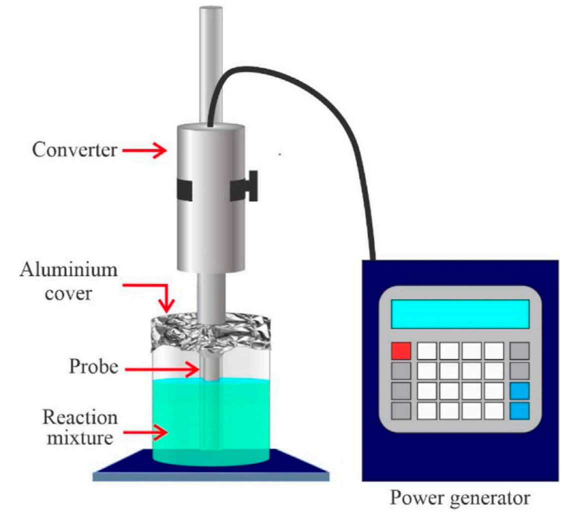

FIGURE 10 | Experimental setup for ultrasound-assisted *in situ* esterification.

tissue cell walls to burst, is connected to the mechanism of action of ultrasound (Suganya et al., 2014). This damage accelerates the mass transfer of the solvent to the matrix's internal area and the soluble components to the solvent, creating turbulence and solvent penetration into the plant matrix, as well as the release of intracellular material. In an ultrasonic bath, in-direct contact ultrasonic extraction was performed. Stevanato and Silva used ultrasound-assisted extraction (UAE) and ethanol as the solvent in their study to extract oil from radish seed (RSO). The temperature had the greatest influence on oil extraction, with a maximum oil yield of 25% reached 60°C, a solvent to seed ratio of 12 ml g1, and a 60-min extraction time (Stevanato and Da Silva, 2019). When compared to the UAE approach, the oil output is reduced by over 50% without the use of ultrasonic. Ultrasound is said to be capable of performing an *in-situ* procedure, in which extraction and transesterification are both accomplished at the same time. Tan et al. did a similar experiment to manufacture biodiesel from *Jatropha Curcas* seed using ultrasonic irradiation. According to their findings, extraction efficiency is about 84% when employing 5% vol H_2SO_4 with a 3:1 solvent-to-methanol volume ratio, a 60% ultrasonic amplitude, and a reaction duration of 150 min with a low acid value of 5.3 mg KOH/g (Tan et al., 2019; Zhang et al., 2019). The experimental setup for ultrasound-assisted surgery is shown in **Figure 10**. Suganya et al. used ultrasonic irradiation to extract and convert the oil from macroalgae *Enteromorpha compressa* biomass utilising tetra hydro furan (THF) as a cosolvent and H_2SO_4 as a catalyst to extract and convert the oil into biodiesel. The parameters used were 30 vol% THF as a co-solvent, 10 wt% H_2SO_4, 5.5:1 methanol to algal biomass ratio, and 600 rpm mixing intensity at 65°C for 90 min of ultrasonic irradiation duration, yielding a maximum biodiesel production of 98.89% (Suganya et al., 2014). Many people believe that ultrasonic irradiation may manufacture the oil's end product in one step (*in-situ*), saving the solvent and catalyst needed in the intermediate steps.

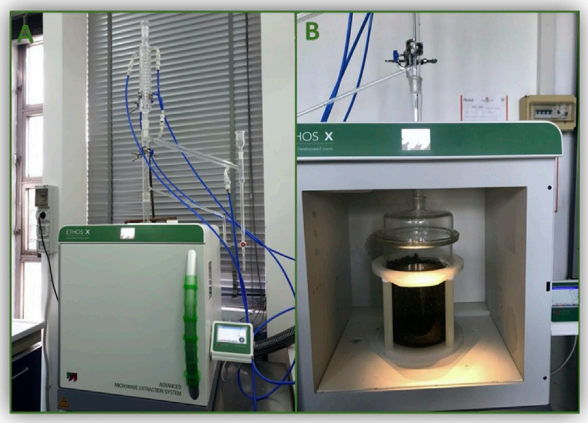

FIGURE 11 | ETHOS X advanced microwave extraction system **(A)**; glass reactor (Pyrex) of 5 L of capacity **(B)** (Fiorini et al., 2020).

Microwave-Assisted Extraction

Suganya et al. used ultrasonic irradiation to extract and convert the oil from macroalgae *Enteromorpha Compressa* biomass utilising tetra hydro furan (THF) as a cosolvent and H_2SO_4 as a catalyst to extract and convert the oil into biodiesel. The conditions were 30 vol% THF as a co-solvent, 10 wt% H_2SO_4, 5.5:1 methanol to algal biomass ratio, and 600 rpm mixing intensity at 65°C for 90 min of ultrasonic irradiation time, providing a maximum biodiesel output of 98.89% (Suganya et al., 2014). Many people believe that ultrasonic irradiation may manufacture the oil's end product in one step (*in-situ*), saving the solvent and catalyst needed in the intermediate steps (Tsubaki et al., 2019). Fiorini et al. employed a microwave-assisted extraction technique to extract *Cannabis Sativa* L. oil, as shown in **Figure 11**. In an optimisation study using a central composite design, the microwave irradiation power (W/g), extraction time (minutes), and water delivered to the plant matrix after moistening (%) were investigated (CCD) (Fiorini et al., 2020). Based on the optimisation results, the maximum oil yield was 0.15% (Fiorini et al., 2020). Ibrahim et al. extract oil from the non-edible *Hura Crepitans* seed, which is native to Nigeria. *Hura Crepitans* is said to be rich in oil, with oil content ranging from 36 to 64%. Extraction parameters such as extraction duration (5–15 min), heating power (180–540 W), solid/solvent ratio (1:10–1:40), and solvent type were optimised (ethyl acetate, n-hexane and acetone). Using an extraction period of 5 min, the heating power of 180 W, a solid/solvent ratio of 1:40, and ethyl acetate as the working solvent, an optimal extraction yield of 72.2 wt% was attained (Ibrahim et al., 2019). Kumar et al. (Kumar et al., 2018) used a redesigned and modified microwave from a commercial microwave to extract oil from *Pongamia Pinnata seeds*. Microwave power levels of 300, 600, and 900 W were used to extract oil, with the results indicating that the optimal conditions were 600 W for 14 min with a yield of 20%.

TABLE 1 | The advantages and disadvantages of extraction.

Extraction methods	Advantages	Disadvantages	References
Mechanical extraction	• When compared to hand pressing, it has a higher oil extraction efficiency (68–80%). • In mechanical extraction, pre-heating may boost efficiency by up to 91%. • No oil contamination with solvent • One of the cheapest extraction process	• Labour and time-intensive • Only applicable for a limited type of feedstock. • Less oil production	Hayyan et al. (2022) Ayoub et al. (2021) Tsubaki et al. (2019) Yate et al. (2020)
Solvent-based extraction (Soxhlet extraction method)	• With a less quantity of solvent, a large amount of plant material may be removed. • The solvent can be used repeatedly. • Does not require filtration after extraction. • Does not depend upon the type of matrix. • A very simple technique. • Several extractions can be conducted in parallel. • able to extract more sample mass than other techniques. • easy continuous operation and ease of automation.	• If the plant material heat-labile chemicals, the danger of thermal destruction of certain compounds will occur occasionally. • The extraction procedure takes a long time and requires a lot of effort. • The method enables the manipulation of a small number of variables. • The quantity of time and solvent required to result in a considerable volume of solvent. • Because of the toxic solvent, it is not environmentally friendly. • Unwanted products and other contaminants should be dissolved.	Rasul, (2018) Ayoub et al. (2021) Haile et al. (2019) Zhang et al. (2019) Guo and Lee, (2011) Cunha and Fernandes, (2018) Zhang et al. (2018)
Supercritical fluid extraction	• The approach is suitable for thermal labile chemicals and is also eco-friendly. • Supercritical conditions and increased solvent solubility result in a greater extraction rate. • Because CO2 is more readily available and inflammable, it is a less expensive solvent to utilise. • A less amount of solvent is used. • Extraction time is reduced.	• A significant of investment cost. • High pressure and temperature are required. • Possibilities of impurities • Compounds that are thermally labile should not be used. • There are several parameters to optimise. • Technical complexity is increasing. • Losses might be variable. • Possibility clogging of the system is a.	Ajila et al. (2011) Ayoub et al. (2021) Xiong and Chen, (2020) Zougagh et al. (2004) Janda et al. (1993) Sairam et al. (2012)
Ultrasound-assisted extraction	• Environmental friendly method • Can replace the solvents with generally recognized as safe solvents • Extraction efficiency is high. • Extraction time is shorter. • Thermo labile chemicals benefit from this. • Process that saves energy. • More time may be spent without changing the molecular structure.	• The dispersion of ultrasonic energy is not uniform. • The use of ultrasonic waves causes the internal structure of chemicals in the oil to degrade. • A large amount of solvent is required.	Ajila et al. (2011) Ayoub et al. (2021) Carreira-Casais et al. (2021) Zougagh et al. (2004) Naziri et al. (2016)
Microwave-assisted extraction	• The extraction time is shorter and higher extraction yield • The use of microwave heating to extract oil eliminates CO$_2$ emissions. • When compared to traditional heating, just a fraction of the energy is used. • Reduce the amount of solvent use.	• When the solvent or desired substance is non-polar or volatile, this approach is ineffective. • High maintenance cost for industrial scale. • No high temperature solution. • The addition of solvent is not permitted in this single step. .	(Danlami et al., 2014) (Ayoub et al., 2021) Gutiérrez-Escobar et al. (2021) Delazar et al. (2012) Jain et al. (2009)

Comparison of Oil Extraction Methods

As previously discussed, several oil extraction techniques have been extensively employed; this section will go through the advantages and disadvantages of each process. The type of feedstock extracted, the cost and the environmental impact of the material used for extractions are frequently taken into account when choosing an extraction process. A part od the rude oil as main product, the biomass waste are the major byproducts of jatropha oil production. Biomass by-products are often discarded into the environment, however, they may be utilised as resin, fertiliser, adsorbent, briquettes, and bioactive compost (Primandari et al., 2018). Based on application, cost, efficiency, and environmental dangers, the advanced of current oil extraction methods have been explored in depth. Therefore, to a get a clear idea on this issue, a critical comparison of several extraction methods are presented in **Table 1**.

CHARACTERISTICS OF *JATROPHA CURCAS* OIL AND BIODIESEL

The properties of vegetable oils significantly differ from diesel fuel, however with an appropriate treatment *Jatropha Curcas* oil can achieve a comparable property as biodiesel and may be used in diesel engines in buses, lorries, cars and other vehicles. It has been successfully tested and has excellent stability at low temperatures, making it an interesting option for use in jet fuels. A study looked at the chemical composition, toxic/anti-metabolic components, and impact of different treatments on their levels in four Mexican *Jatropha Curcas* provenances (Herrera et al., 2006). The authors looked at the proximate composition, total soluble sugars, and starch content of *Jatropha Curcas* seed kernel meal from a range of agroclimatic zones in Mexico. The crude protein (31–35%), and fat levels of the samples differed somewhat (55–58%). Coatzacoalcos has a crude protein percentage of 62.0%, whereas Castillo de Teayo has a crude protein value of 65.0%. The crude protein content of the samples was greater in several treatments. The fibre level of *Jatropha Curcas* meals was lower than that of soybean meal in their research but equivalent to other seed provenances from Cape Verde (4.7%), Senegal (5.6%), Burkina Faso (5.3%), India (4.5%), and Nicaragua (4.5%). (4.5%). 4.5% 3.8% point (pp. 86, 87). Whole kernels had comparable gross energy content (31.1–31.6 MJ/kg). Both total soluble sugars and starch content were less than 6%. The researchers used previously available information to compare the fatty acid composition of three *Jatropha Curcas* seed oils. All of the oil samples included oleic, linoleic, palmitic, and stearic fatty acids. Oleic acid was the most common fatty acid in the Veracruz samples, whereas linoleic acid was the most frequent fatty acid in the Morelos samples. This variation might be due to soil and climatic conditions. According to the study, unsaturated fatty acids make up the majority of the oil (oleic and linoleic acid). The results are quite comparable to those published earlier for *Jatropha Curcas* seed provenances from other countries (Banerji et al., 1985; Nasir et al., 1988; Gübitz et al., 1999).

The most prevalent fatty acid in crude *Jatropha Curcas* oil (CJCO) is oleic (44.5%), followed by linoleic (35.4%), palmitic (13.1%), and stearic (13.1%), 5.8% of the population. Because it contains 80.9% unsaturated fatty acids, CJCO has outstanding low-temperature properties (oleic and linoleic acids). In crude *Calophyllum Inophyllum* oil (CCIO), unsaturated fatty oleic (46.1%) and linoleic acid (24.7%) are discovered in higher quantity than saturated fatty palmitic acids (14.7%) and stearic acid (13.2%). In addition, crude *Calophyllum Pentandra* oil (CCPO) contains 39.7% linoleic acid, 19.2% palmitic acid, and 18.5% malvaloyl acid. Sarin et al., and Abdullah et al., respectively, reported similar CJCO, CCIO, and CCPO composition findings (Abdullah et al., 2010; Sarin et al., 2010). Emil et al. (Emil et al., 2010) was extracted oil from *Jatropha Curcas* seeds taken from Malaysia, Indonesia, and Thailand, and the fatty acid content (FAC) was determined using gas chromatography (GC). They discovered that oleic acid (42.4–48.8%) and linoleic acid (28.8–34.6%) are the most abundant fatty acids in *Jatropha Curcas* oil. Saturated fatty acids like palmitic and stearic acid have molecular weights of 13.25–14.5 and 7–7.7%, respectively. **Table 2** presents FAC of *Jatropha Curcas* oil by various studies.

Numerous researchers investigated the physicochemical and thermal characteristics of *Jatropha Curcas* oil. For example, Mohammed-Dabo et al. (Mohammed-Dabo et al., 2012) evaluated the fatty free acid (FFA) content, viscosity, calorific value, acid, iodine, saponification parameters, and cetane number of Nigerian *Jatropha Curcas* seed oil. **Table 3** shows the key physicochemical characteristics of raw *Jatropha Curcas* oil provided by important studies.

The characteristics of *Jatropha Curcas* biodiesel are crucial since they define the fuel's ultimate attributes. Vegetable oil's increased viscosity is a key drawback when used as a diesel engine fuel. The viscosity of biodiesel is reduced when it is converted. The fatty acid content of biodiesel is closely related to its characteristics. The structural fatty acid content of non-edible oil, which has a substantial number of double carbon chains, affects biodiesel physicochemical qualities such as cetane number, oxidation stability, the heat of combustion, and viscosity (Atabani et al., 2013). These properties indicate the quality of the fuel. The kinetic viscosity of the fuel determines its flow, spray, and atomisation properties. High viscosity reduces spray and atomisation and increases fuel consumption thus less viscosity is conducive for better performance (Arbab et al., 2013; Kuti et al., 2013). High density creates high viscosity, which causes inefficient combustion, poor engine performance, and poor emission characteristics (Alptekin and Canakci, 2009; Arbab et al., 2013). Cetane No. (CN) is connected to ignition delay time, or the interval between fuel injection and ignition. A greater CN causes a shorter ignition delay. For CI engine fuel, a higher CN is desired (Razak et al., 2021). A fuel's heating value is the amount of heat created during burning per unit of fuel. Fuel with a higher heating value is preferred since it helps combustion and increases engine performance (Arbab et al., 2013). According to Pinzi et al. (Pinzi et al., 2009) a longer carbon chain length results in a greater heating value, which has a significant impact on biodiesel's cold flow properties. **Table 4** shows a comparison of physicochemical properties of *Jatropha Curcas* biodiesel and diesel and corresponding biodiesel standard in Europe.

The effectiveness of centrifugal separators to remove pollutants is influenced by their density. The centrifugal cleaning process is driven by the density differential between the impurities in the fuel and the fuel oil itself. Amidst this comparison, biodiesel produced from *Jatropha Curcas* oil showed a density of 879 kg/m^3 (Foidl et al., 1996) 876.2 kg/m^3 (Sarin et al., 2007), 876.2 kg/m^3 (Dharma et al., 2017), respectively, which are fulfilling the requirement the limits stated by European legislation. Viscosity, which is also an essential attribute of lubricants, is one of the most significant fuel qualities of biodiesel and diesel fuel generated from petroleum. Various biodiesel and diesel standards specify allowable kinematic viscosity ranges. The viscosity of biodiesel must be below 5 mm^2/s and 6 mm^2/s as required by EN ISO 3104 and D445, respectively, to achieve complete combustion with minimum coke deposit in the engine. *Jatropha curcas* has a viscosity of 4.84 cSt (Foidl et al., 1996), 4.16 cSt (Sarin et al., 2007) and 4.57 cSt (Dharma et al., 2017), respectively. All viscosity met the requirement stipulated in the ASTM D445 method. Although the actual viscosity of biodiesel depends on the fatty acid composition of the oil or fat from which it is made and also on the extent of oxidation and polymerization of the biodiesel. The lowest temperature at which a fuel generates enough vapour to induce ignition and flame production is known as the flash point. The flash point of biodiesel is greater than that of normal diesel. Furthermore, biodiesel's flash point criteria is greater than

TABLE 2 | Fatty acid composition of the *Jatropha Curcas* oil.

Fatty acids (no of carbon atoms:degree of unsaturation)	Fatty acid relative composition (%) in oil				
	Emil et al. (2010)	Foidl et al. (1996)	Sarin et al. (2007)	Ashraful et al. (2014)	Kumar and Sharma, (2011)
Decanoic acid (10:0)	—	0.1	—	—	—
Myristic acid (14:0)	0.1	0.1	—	1.4	1.4
Palmitic acid (16:0)	13.2–14.5	13.6–15.1	14.2	13.6–15.1	15.6
Palmitoleic acid (16:1)	0.6–0.7	0.8–0.9	1.4	0.8–0.9	—
Stearic acid (18:0)	7.0–7.7	7.1–7.4	6.9	7.1–7.4	9.7
Oleic acid (18:1)	42.4–48.8	34.3–44.7	43.1	34.3–44.7	40.8
Linoleic acid (18:2)	28.8–34.6	31.4–43.2	34.4	31.4–43.2	32.1
Linolenic acid (18:3)	0.1–0.2	0.2–0.3	—	0.2–0.3	—
Arachidic acid (20:0)	0.2–0.3	02.-0.3	—	02.–0.3	0.4
Behenic acid (22:0)	—	0.2	—	—	

TABLE 3 | The physicochemical characteristics of *Jatropha Curcas* oil.

Parameter	Emil et al. (2010)	Bilal et al. (2013)	Mohammed-Dabo et al. (2012)	Foidl et al. (1996)	Samniang et al. (2014)
%FFA	1.69–9.20	14.6	14.8	0.29–1.27	—
Iodine value	92.53–107.57	—	100.56	95.2–106.6	84.2
Saponification value	193.55–216.09	198.76	202.34	190.1–192.4	199.2
Density (kg/m^3)	902.4–909.5 (at 20 °C)	920.4	874	920	—
Kinematic Viscosity (cSt)	39.20–53.94 (at 40 °C)	66.74	—	37–38.8 (at 30 °C)	33.55 (at 40 °C)
Acid value (mg KOH/g)	—	29.06	29.6	0.92	7.0

TABLE 4 | Fuel properties comparison *Jatropha Curcas* biodiesel and mineral diesel and corresponding biodiesel standard for Europe.

Properties	***Jatropha Curcas*** **Biodiesel (Foidl et al., 1996)**	***Jatropha Curcas*** **biodiesel (Sarin et al., 2007)**	***Jatropha Curcas*** **biodiesel (Dharma et al., 2017)**	**Mineral Diesel**	**EN 14214 (Tsoutsos et al., 2019)**
Density (kg/m^3) at 15 °C	879	—	876.2	840 ± 1.732	860–900
Kinematic Viscosity at 40 °C (cSt)	4.84	4.16	4.57	2.44 ± 0.27	3.4–5.0
Pour Point (°C)	3 ± 1	—	2	6 ± 1	N.A.
Flash Point (°C)	191	163	125.5	71 ± 3	Min. 101
Conradson Carbon residue (%, w/w)	0.01	< 0.01	—	0.1 ± 0.0	Max. 0.05
Oxidation stability (h)	—	3.23	14.01	—	Min. 8 h
Acid value (mg KOH/gm)	0.24	0.48	0.46	—	Max 0.5
Sulphated ash (%, w/w)	0.014	0.002		0.01 ± 0.0	Max. 0.02
Calorific Value (MJ/kg)	38.5	—	39.46	45.343	—
Sulphur (% w/w)	< 0.001	0.004	—	0.25	Max. 0.05
Carbon (% w/w)	77.1	—	—	86.83	—
Hydrogen (% w/w)	11.81	—	—	12.72	—
Oxygen (% w/w)	10.97	—	—	1.19	—
Cetane No.	51–52	57.1	59 (Cetane index)	48–56	Min 51
Free glycerol (% mass)	0.015	0.01		—	Max 0.020
Total glycerol (% mass)	0.088	0.02		—	Max 0.250

that of diesel requirements. Biodiesel has a flash point of 150°C on average, while diesel fuel has a flash point of 55°C–66°C (Tat and Van Gerpen, 1999). FP was measured through EN ISO 3679 and ASTM D93. The flash point of the Jatropha Curcas Biodiesel was 191°C (Foidl et al., 1996), 163°C (Sarin et al., 2007), 125.5°C (Dharma et al., 2017) respectively, which is slightly lower than palm biodiesel (182.5°C) but higher than CI biodiesel (123.5°C), the reported flash point is still in the range stipulated in both test method. Calorific value is defined as the amount of heat emitted by a fuel when it is entirely burned and measured at a constant volume or constant pressure, with the hot gas cooled to its original temperature (Sharudina et al., 2018). Based on EN 14213, the calorific value should be higher than 35 MJ/kg. The calorific value was 38.5 MJ/kg (Foidl et al., 1996) and 39.46 MJ/kg (Dharma et al., 2017). The acid number (AN) is one of the analytical parameters usually employed to evaluate the quality of biodiesel. It represents the corrosive potential of biodiesel, which can reduce the lifetimes of fuel tanks and vehicle engines. The

ASTM D 6751 biodiesel acid-number limit was harmonized with the European biodiesel value of 0.50. ASTM D 664 is the standard reference method for measuring the acid number of both ASTM biodiesel and petroleum-derived diesel. The existing literature revealed *Jatropha Curcas* has a near the borderline of 0.24 mg KOH/g (Foidl et al., 1996), 0.48 mg KOH/g (Sarin et al., 2007) and 0.38 mg KOH/g (Dharma et al., 2017), respectively. Oxidation stability is the important property of fatty acid methyl esters and affects biodiesel primarily during extended storage. Biodiesel tends to be less resistant to oxidation than petroleum diesel. Thus, the higher the unsaturated chain of fatty acids, the lower its stability. The oxidation process was initiated with peroxides, forming a volatile organic compound such as aldehydes and ketones. The minimum induction time according to ASTM D6751 is 3 h. *Jatropha Curcas* exhibits an oxidation time of 3.23 h (Sarin et al., 2010), and 14.01 h (Dharma et al., 2017) shows superior oxidation stability. It can be shown that the stability of biodiesel is strongly influenced by the makeup of unsaturated esters. Polyunsaturated esters are much more susceptible to oxidation than saturated or monounsaturated esters.

ENGINE PERFORMANCE AND EMISSION OF USING *JATROPHA CURCAS* BASED BIODIESEL

Biodiesel fuels have a greater oxygen concentration, they burn more efficiently (Elkelawy et al., 2019). To evaluate engine performance, the researchers usually look at 1) engine torque, 2) brake power (BP), 3) brake specific fuel consumption (BSFC), 4) brake specific energy consumption (BSEC), 5) brake thermal efficiency (BTE), and 6) exhaust gas temperature (EGT). To investigate the emissions, the authors usually examine 1) nitrogen oxides (NO_x), 2) hydrocarbon emissions (HC), 3) carbon dioxide (CO_2), 4) carbon monoxide (CO), and 5) smoke opacity (SO). In certain circumstances, blended biodiesel outperforms regular diesel fuel in terms of BP (Sahoo et al., 2009; Fattah et al., 2014). Some researches have shown that using jatropha biodiesel reduces BTE (Chauhan et al., 2010; Kathirvelu et al., 2017). BP drops as the amount of biodiesel in the fuel blend increases (Thapa et al., 2018). BTE, on the other hand, diminishes when the amount of *Jatropha* biodiesel in the fuel mix grows (Madiwale et al., 2018). The increasing proportion of *Jatropha* biodiesel in the diesel–biodiesel blend reduces HC emissions (Chauhan et al., 2012). Reksowardojo et al. (Reksowardojo et al., 2007) reported that when compared to diesel fuel, an increase in biodiesel percentage results in a reduction in HC emissions of 14.91–27.53 percent. Lower HC emissions are usually observed at full load conditions than other load conditions (Senthilkumar and Sankaranarayanan, 2016). In most cases, the NOx emissions from *Jatropha* biodiesel are greater than those from diesel fuel (Abed et al., 2019). CO emissions from *Jatropha* biodiesel and its blends are usually reduced by 10–40% compared to that of diesel at full load condition (Huang et al., 2010; Singh A. et al., 2021). The rise in CO emissions is noticed when the load percentage increases (Sundaresan et al., 2007). Smoke opacity falls as the biodiesel content in the blend rises, but increases when the load increases for *Jatropha* biodiesel and its blends (Chauhan et al., 2012; Pandhare and Padalkar, 2013). The engine performance and emissions while utilising *Jatropha Curcas* based biodiesel for different test conditions are summarised in **Table 5**.

Economic Viability of *Jatropha* Biodiesel Production

Francis et al. (Francis et al., 2005) reported that *Jatropha Curcas* thrives on underutilised locations with little water and poor soil, according to reports, and it may yield oilseed as early as the first year of growth, although on a small scale. In the tropics, the feasibility of commercialising *Jatropha* cultivation on fertile land to replace other food and income crops has been questioned. In the tropics, the feasibility of commercialising *Jatropha Curcas* cultivation on fertile land to replace other food and income crops has been questioned. Wahl et al. (Wahl et al., 2009) reported that Based on a yield of 2000 kg per year from mature trees, yearly operational expenditures for 1 ha of *Jatropha Curcas* are estimated to be about USD 200. Picking and post-harvest processing make for a large number of total expenses, they said. Thus annual expenditures are strongly reliant on production. Because *Jatropha Curcas* growing requires a lot of labour, it's difficult to achieve or sustain economic viability. *Jatropha Curcas* can be intercropped with annuals, perennials, or trees which boosts soil productivity acts as a soil cover and gives instant extra revenue to farmers (Wahl et al., 2009). When *Jatropha Curcas* production is low or nonexistent, yet land maintenance and opportunity expenses must be paid, this is required the most. The less space between rows for intercrops, the more soil the *Jatropha Curcas* plants cover. As a result, intercrop output declines with time, which does not always correspond to an increase in *Jatropha Curcas* yield. The use of *Jatropha Curcas* species local to specific countries, as well as the development of *Jatropha Curcas* on degraded lands that cannot now be used for agriculture, would be less problematic and more acceptable. Navarro-Pineda et al. (Navarro-Pineda et al., 2017) investigated Biodiesel production from *Jatropha Curcas* in Yucatán state, Mexico: economic feasibility and energy balance The nett energy ratio of biodiesel production is 2.88 when all energy outputs (glycerine, press cake, and pellets) are taken into account. The system generates more energy than it consumes if the nett energy ratio is larger than one. Biodiesel production, however, is not economically feasible based on the criteria used in this study. They estimated that achieving economic viability would need a seed yield of 3,250 kg/ha per year. As a result, future research should concentrate on inventing, developing, and improving technology to modernise the seed gathering, seed processing, oil extraction, and biodiesel manufacturing processes. The agronomic performance, water and nutrient requirements, and pest and disease susceptibility of Jatropha should be examined in more detail for commercial and economically successful production.

TABLE 5 | Summary of the review of engine performance and emissions by using *Jatropha Curcas* based biodiesel.

References	Scope of the study	Performance findings	Emission findings
Rajak et al. (2020)	Performance and emission of JB20, JB40, JB60 were evaluated in a single-cylinder diesel engine operating at 1,500 rpm with CR[a] 18.5 and at various loads (25, 50, 75, and 100%)	• The BTE values for JB20 are slightly lower (0.5–2.06%) and • The BSFC values for JB20 are more (3.6–2.2%) compared to diesel fuel	• At all engine loads, the NO_x emission was lower for *Jatropha* Curcas blends • *Jatropha* Curcas blends were found to lower smoke emission
Dharma et al. (2017)	Performance and exhaust emissions of a single-cylinder DI diesel engine fuelled with biodiesel-diesel mixes made from *Jatropha-Curcas* and *Ceiba Pentandra*. Blending 10, 20, 30, 40, and 50 vol% of J50C50 biodiesel with diesel yields B10, B20, B30, B40, and B50 blends.	• When compared to other fuel mixes, the B10 blend has greater engine torque, braking power, and BTE, with values of 34.07 Nm, 3.5 kW, and 34.1%, respectively.	• For all of the J50C50 biodiesel-diesel blends studied in this research, the B10 blend had the lowest CO, NO_x, and SO values at an engine speed of 1900 rpm.
Kavitha et al. (2019)	Three mixes are available: 90% diesel, 7.5% JB, and 2.5% ethanol (D 90J7.5E1.25), 95% diesel, 3.75% JB, and 1.25% ethanol (D95J3.75E1.25), and 98% diesel, 1.5% JB, and 0.5% ethanol (D 95J3.75E1.25) (D98J1.5E0.5).	• When compared to diesel, the BTE of D90J7.5E2.5 and D95J3.75E1.25 rose by 2.13 and 3.24%, respectively, at 0.937 kW. When compared to diesel, the BSFC of the blend D90J7.5E2.5 fell by 2.68% at 0.937 kW.	• When compared to diesel, D90J7.5E2.5 shows a moderate reduction in NO_x emissions, whilst D95J3.75E1.25 shows a slight rise in NO_x emissions. • Increasing biodiesel mix lowered HC and NO_x emissions while reducing biodiesel blend reduced CO emissions.
Xu et al. (2017)	Under light load operation of a diesel engine, the influence of fuel supply parameters on performance and emission characteristics of a 20% mix of *Jatropha Curcas* biodiesel (J20).		
Rashed et al. (2016)	In a diesel engine, the performance and emissions of moringa biodiesel (20%) were examined and compared to palm, *Jatropha Curcas*, and diesel fuel.	• The average BP for biodiesel fuel blends was somewhat lower (6.92–8.75%) than diesel, whereas BSFC values were higher (5.42–8.39%).	• Biodiesel blends significantly decreased CO (22.93–32.65%) and HC (11.84–30.26%) emissions, but somewhat increased NO (6.91–18.56%) emissions when compared to diesel fuel.
Sahoo et al. (2009)	Biodiesel (B20, B50, and B100) compares to diesel in terms of performance and emissions.	• For a full load, the use of JB20 and JB50 showed 0.09–2.64% and 0.05–3.8% improvement in power respectively. • Change in BSEC for JB20, JB50, JB100 were 2.86, 6.0, 12.37% at rated speed, respectively.	• The reduction in smoke for JB20, JB50, and JB100 at full load and rated speed was 28.57%, 40.9%, and 64.28%, respectively.
Ong et al. (2014)	JB10, JB20, JB30, and JB50 engine performance and emissions were tested in a diesel engine at full load.	• The lowest BSFC 261 g/kWh, 281 g/kWh and 290 g/kWh at 1900 rpm were reported for JB10 and the highest BSFC was 401 g/kWh, for JB50 at 2,400 rpm. • JCB resulted in higher BTE compared to other tested biodiesels	• JB10 had the lowest NO_x of 86.10 ppm at 1900 rpm and the highest NO_x of 120.36 ppm at 2,400 rpm • They reported a decreased HC emission for JB10 compared to diesel
Chauhan et al. (2010)	Preheated *Jatropha Curcas* oil's performance and emissions in a medium-capacity diesel engine	• Preheated *Jatropha Curcas* oil is indicated as a viable diesel engine fuel replacement. • Considering the BTE (brake thermal efficiency), BSEC, and gaseous emissions, 80°C was determined to be the best fuel input temperature. • The BTE of *Jatropha Curcas* oil that had been warmed was greater than that of unheated *Jatropha Curcas* oil. • Jatropha oil (unheated or warmed) has a greater BSEC than diesel.	• Unheated *Jatropha* Curcas oil emits more CO than diesel fuel or warmed *Jatropha Curcas* oil. • HC emissions are lower with warmed oil at 100 °C than with diesel.
Elango and Senthilkumar, (2011)	Performance and emission characteristics of a diesel engine running on various *Jatropha Curcas* oil/diesel mixtures (10–50%).	• The BSFC of B20 is somewhat greater than diesel, although other mixes are closer to diesel. • For the same power output, B20 obtained a maximum brake thermal efficiency of 29.4%, while diesel reached 30.9%.	• The exhaust gas temperatures were greater because the engine was air-cooled, which increased NO_x emissions. • Blends of up to 20% lowered CO_2 emissions significantly while just slightly lowering BTE.

(Continued on following page)

TABLE 5 | (*Continued*) Summary of the review of engine performance and emissions by using *Jatropha Curcas* based biodiesel.

References	Scope of the study	Performance findings	Emission findings
Agarwal and Agarwal, (2007)	The effect of raising the fuel temperature to reduce the viscosity of *Jatropha Curcas* oil on the engine's combustion and emission characteristics	• When comparing diesel with heated *Jatropha Curcas* oil, the BSFC and EGT for unheated Jatropha oil were shown to be greater. • Unheated *Jatropha Curcas* oil has a lower BTE than heated *Jatropha Curcas* oil and diesel.	• In comparison to diesel, emission characteristics rose as the quantity of *Jatropha Curcas* oil in the blends increased. • For warmed *Jatropha Curcas* oil, CO_2, CO, HC, emission, and smoke opacity were found to be comparable to diesel.
Forson et al. (2004)	In a single-cylinder direct-injection diesel engine, the performance of *Jatropha Curcas* oil and diesel mixtures. Diesel, Jatropha Curcas oil, and diesel/*Jatropha Curcas* oil blends of 97.4%/2.6%, 80/20%, and 50/50 by volume were used in the tests.	• The best braking power, thermal efficiency, and specific fuel consumption were attained using a 97.4% diesel/2.6% Jatropha blend.	• CO readings are lower at higher loads (higher than 4 Nm) for fuels with less than 2.6% oil by volume.
Senthil Kumar et al. (2003)	Single fuel operation in a single-cylinder direct injection diesel engine at 1,500 rpm using plain *Jatropha Curcas* oil and its esters (100% JB) as fuel.	• When compared to diesel, *Jatropha Curcas* oil had a somewhat lower BTE. • Maximum BTEs are 27.4, 29 and 30.2% with *Jatropha Curcas* oil, JB and diesel.	• Compared to diesel, both *Jatropha Curcas* oil and JB emit more HC than diesel, with increases of 10 and 30% respectively. • CO_2 emissions followed a similar pattern. • *Jatropha Curcas* oil and JB had maximum smoke levels of 4.4 BSU and 4 BSU, respectively. It is 3.8 BSU[b] in the case of diesel.

[a] *Compression ratio.*
[b] *Bosch Smoke Units.*

FUTURE RESEARCH DIRECTIONS

Biodiversity is important in supporting ecosystem processes and may be thought of as a basis for ecosystem services. It may also function as an ecological service in and of itself (Mace et al., 2012). The following elements are regarded as important drivers of biodiversity loss connected with biofuels: 1) habitat degradation or change in land use, 2) species invasiveness, 3) pollution, and 4) climate change Among them, habitat degradation is recognised to be a significant contributor to biodiversity loss, followed by species invasiveness (Kgathi et al., 2017). It has not yet been possible to get significant and sustainable volumes of *Jatropha* oil for large-scale biodiesel manufacturing. As a result, the development of new Jatropha projects has been slowed, and numerous current initiative projects have been cancelled (Ewunie et al., 2021). Insufficient market opportunity, insufficient government incentives, lack of clear regulations and legislation, ownership issues, arable land scarcity, inadequate technology in seed collecting and processing, and poor agronomic performance Jatropha seed were the key obstacles to sustainable *Jatropha* biodiesel production.

Engine types, operating procedures, combustion processes, and diverse biodiesel fuel attributes all have a substantial impact on the performance, combustion, and emission characteristics of diesel engines running on *Jatropha* biodiesel. Extensive experimental effort on molecular and genetic enhancement is also required to provide enough and high-quality feedstock for long-term biodiesel production. Future research should concentrate on either increasing the fuel qualities of Jatropha biodiesel and modifying diesel engines to improve performance and emission characteristics. Finally, before developing large-scale biodiesel production, the economic, social, environmental, and technological potential of Jatropha for sustainable biodiesel production should be studied.

CONCLUSION

The properties and performance of biodiesel made from *Jatropha* were examined and reported. In terms of raw resources, *Jatropha*-based biodiesel does not compete with human food because of the existence of certain harmful components, non-edible plant oils are not acceptable for human consumption, according to tests conducted around the world and findings available in the literature. *Jatropha* plants, unlike other food plants, do not need rich soil. These plants are widely accessible in underdeveloped nations, and they are particularly cost-effective when compared to edible plant oils. When utilised in an internal combustion engine, *Jatropha*-based biodiesel produces less pollution. The engine performance of *Jatropha* biodiesel is equivalent to that of petroleum-based diesel. Good economic performance and necessary public policies are essential components in achieving commercial *Jatropha*-based biodiesel manufacturing success. However, *Jatropha* biodiesel is made through a simple triglyceride and fatty oil transesterification process that is aided by alkaline or acidic catalytic agents. The latter has a number of drawbacks; researchers have looked for enzymes that are less harmful to the environment. Furthermore, in order to maximise productivity, effective agricultural techniques that match local environmental circumstances must be used (soil, climate, etc.). Because fossil fuel (coal, oil, and gas) reserves are fast depleting, it is predicted that *Jatropha*-based biodiesel will be a viable long-term alternative. Because these fossil fuel resources are limited, if they are used over an extended period of time, global resources will ultimately run out. To summarise, the Jatropha is differentiated by the many ecological, energy, and economic advantages connected with its commercial usage, and increased use of this plant is helpful to the environment and food production.

AUTHOR CONTRIBUTIONS

TR wrote the manuscript, reviewed, improved, and compiled the whole article. AS and YP contributed to conceptualization and writing the extraction section. AS contributed to the methodology section. IF contributed to the introduction section. TM and HO oversaw the work and provided review. All authors contributed to the article and approved the submitted version.

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