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EXTRACTION TECHNIQUES AND INDUSTRIAL APPLICATIONS OF JATROPHA CURCAS

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Graphical abstract

Abstract

The fact that *Jatropha curcas* oil cannot be used for nutritional purposes without detoxification makes its useful as energy or fuel source, which will improve the domestic economy and provide job opportunities particularly in rural areas, where mechanical pressing is currently the most extensively used process to extract oil from seed. In this context, the main goal of this study is to provide a summary of several studies dealing with the currently employed oil extraction technologies, the physicochemical properties of bio-oils obtained from *J. curcas*, and the potential uses of *Jatropha* oil. The aim is to shed light on the main differences among the four types of oil extraction techniques currently employed and to highlight their most appropriate applications. If tapped efficaciously, then these techniques could prove to be extremely helpful in these days of power and environmental crises.

Keywords: *Jatropha curcas*, Extraction technique, Industrial applications, Potential uses

1.0 INTRODUCTION

Consumer demand for oil, oil-based products, and products produced with oil continues to increase. Moreover, the increase in volatility, industrialization, and modernization of the world's oil market has, in turn, increased the prices of oil, biodiesel, and bitumen. Other by-products of petroleum also vary with the increase in the price of petroleum. The buying price of petroleum in industries and the market continuously increase with the increase in consumption degree. Extra expense stems from adherence to environment laws, which increases the discharge of hazardous substances. Reducing the need for oil, oil-based goods, and merchandise produced together with oil within the concrete manufacturing industry is, as a result, critical if the marketplace is to stay competitive in the global market place [1]. Given the ever-increasing demand for natural petroleum and its unstable price and severe effect on the environment and the health of workers, fossil fuel will become rare and faces serious shortage in the near future. The negative effects of fossil fuel-based products on the ecosystem increase the search for new raw materials and improved technologies [2]. The existing utilization of bio-based resources on material functions will become negligible compared with traditional nonrenewable sources. The primary reason is that these kinds of materials in many cases are less developed because the price of the standard materials of certain goods or materials is high. Nonetheless, the use of bio-based materials within the civil engineering field may cause a lowered environmental influence and might lead to the decrease in expense during the creation of revolutionary products, which demand lasting procedures and eco-innovation in material development with regard to engineering application and mass buyers [3, 4].

Improved techniques use fresh materials and their advancement has to be knowledge-based. Meanwhile, prevalent issues tend to be useful because of resource saving and variability within properties, such as functionality, light, lower costs, and eco-efficiency, at all stages of the item lifestyle routine. Necessities, such as requirements, that should be fulfilled include the utilization of garbage for biomass, muscle, wood removal ingredients, and biopolymers to supply limbs associated with size consumer products, car manufacturers, and market sectors [5].

Researchers and industries have been seeking new technologies and approaches to reduce the use of petroleum products. Using alternative materials is one of the most effective and environmentally friendly ways to solve this problem. Bio-oil, also known as pyrolysis oil, microalgae bio-oil [6], bio-crude oil, vegetable oil, forest and agricultural waste oil, and energy crop oil, wood liquids, wood oil, liquid smoke, pyroligneous acid, and liquid wood, can be described as dark brown, free-flowing organic liquids produced from the rapid heating of biomass under vacuum conditions [7]. Bio-oil is composed of a wide range of chemicals that are derived from depolymerization, catalytic transesterification, and degradation of cellulose, hemicellulose, and lignin. Bio-oil, as a renewable fuel, can directly substitute liquid transportation fuel, partially replace bitumen, and produce high-value chemicals because of its low pollutant emission [8]. One of the agricultural renewable sources of energy is vegetable oil. Vegetable oil is a basic raw material for the production of biofuel or biodiesel. More than 350 oil-bearing species exist in the world, but only 63 of these species belong to 30 plant families; these species are considered potential sources for biodiesel production in different countries, depending on climate and agriculture [9]. Among the different oil-bearing species in the world, the inedible nature of *Jatropha curcas* is one of its attractive points [10].

2.0 INTRODUCTION OF JATROPHA CURCAS

2.1 Jatropha curcas

Jatropha curcas (physic nut) belonging to the Euphorbiaceae family, a native of tropical America, has been introduced into Africa and Asia and is now cultivated worldwide over an area of approximately 1 million ha [11-13]. Studies and forecasts by the Global Social Investment Exchange indicate a strong expansion in the cultivation of this crop by up to 12.8 million ha in 2015. Another study by the International *Jatropha* Organization confirmed the trend, with a forecast of 160 million tons of seeds from 32.72 million ha cultivated worldwide by 2017. *Jatropha* is a genus of approximately 175–200 plants [9, 13, 14], shrubs, and trees adapted to arid conditions, which can easily be propagated by cutting, and is extensively planted with a built-in capacity to combat desertification by restoring vegetative cover. Jatropha seeds contain around 47.25 ± 1.34% of crude oil, the remainder being proteins (24.60 ± 1.40%), water (5.54 ± 0.20%), crude fibers (10.12 ± 0.52%), ash (4.50 ± 0.14%) and carbohydrates 7.99% by difference. The plant is also relatively drought resistant and has potential for controlling soil erosion and increasing the habitat of wild animals. The plant does not require any particular soil type for growth, can flourish on almost any soil composition, and can produce seeds containing up to 40% mass of oil [15-17].

Figure 1 *Jatropha* plant and seed

Jatropha's ability to grow on marginal, waste, or arid land and produce energy crops without displacing food crops is perhaps of utmost potential and importance to the developing world, particularly as we face the effects of climate change. The benefits for the developing world go further than producing fuel for local use, its capability to grow on marginal land, and its ability to reclaim problematic lands and restore eroded areas. Given that *Jatropha* is not a forage crop, it plays an important role in keeping out cattle and protecting other valuable food crops or cash crops. *Jatropha* products from the fruit—the flesh, seed coat, and seed cake—are rich in nitrogen, phosphorous, and potassium and are fertilizers that improve soil. Bio-diesel from *Jatropha* is self-sufficient for transportation, industries, and rural electrification [12, 13, 18, 19].

With increased awareness of energy security and global warming, *Jatropha curcas* oil has been the focus of increasing interest in the past few years as a new biofuel crop particularly because it is a non-edible oil that cannot be used for nutritional purposes due to the presence of anti-nutritional factors, such as phorbol esters, its availability, and its less expensive vegetable oil. Thus, *Jatropha curcas* oil is considered a more sustainable feedstock for energy production than any other food-based crop, such as palm oil, rapeseed oil, soy bean oil, and sun flower oil [16, 20-22].

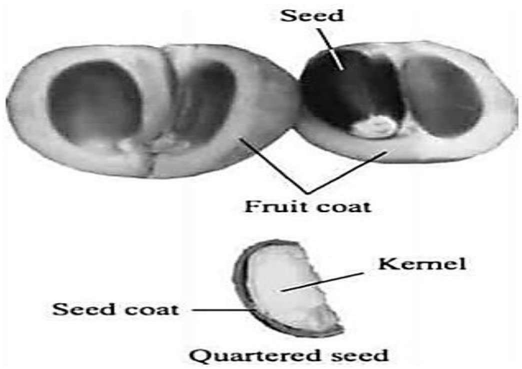

Figure 2 Section of the fruit and seed of *J. curcas*

2.2 Physical Properties of Jatropha curcas Oil

Notably, oil with high iodine, cloud, and pour point values exhibits poor cold performance. Oxidation of lipids is a major cause of their deterioration, and hydrogen peroxide formed by the reaction between oxygen and unsaturated fatty acids are the primary products of these reactions. Hydrogen peroxide has no flavor or odor but breaks down rapidly to form aldehydes, which have disagreeable flavor and odor.

Table 1 Physical properties of *Jatropha curcas* seed oil

Property	**Value**
Boiling point	124 °C
pH	5.2
Free fatty acids	0.0718 mg KOH g^{-1} oil
Specific gravity	0.8480
Flash point	150 °C
Cloud point	14 °C
Saponification value	155 mg KOH g^{-1} oil
Peroxide value	7.20 meq g^{-1} oil
Iodine value	51.27 g 100 g^{-1} oil
Dielectric strength	22 kV
Pour point	4 °C
Density at 27 °C	0.725 g cm^{-1}
Acid value	0.1428 mg KOH g^{-1} oil
Viscosity	8.2 cst

In this case, Table 1 shows that *Jatropha curcas* has an iodine value of less than 100, pour point of 4 °C, and cloud point of 14 °C, indicating that the oil is non-dry oil that can perform satisfactorily even in cold climatic conditions. A low peroxide value increases the suitability of the oil. The oil can be stored for a long time because of its low levels of oxidative and lipolytic activities. The lower the oil viscosity, the easier it is to pump and atomize and to achieve finer results. Oils with flash point greater than 66 °C are considered safe oils. With a flash point of 150 °C, *Jatropha curcas* oil can prevent auto ignition and fire hazard at high temperatures during transportation and storage [18, 23-28].

2.3 Fatty Acid Composition

Table 2 shows that fatty acid compositions of vegetable oils. Vegetable oils contain oleic acid (C18:1) and linoleic acid (C18:2), which are major fatty acids. The fatty acid composition of most triglyceride biomasses is 19.80 ± 11.09% palmitic acid (C16:0), 9.08 ± 6.86% stearic acid (C18:0), 37.68 ± 16.33% oleic acid (C18:1), and 25.30 ± 21.63% linoleic acid (18:2).

Table 2 Fatty acid composition of *Jatropha curcas* seed oil [1, 29]

Fatty acid composition	**(%)**
Palmitic (C16:0)	11.3
Linoleic (C18:2)	47.3
Oleic (C18:1)	12.8
Stearic (C18:0)	17
Palmitoleic (C16:1)	0.7
Linolenic (C18:3)	0.2
Arachidic (C20:0)	0.2
Margaric (C17:0)	0.1
Myristic (C14:0)	0.1
Saturated	21.6
Monounsaturated	45.4
Palmitic (C16:0)	11.3

2.4 Lignin Content of *Jatropha curcas*

Lignin is one of the most vital amorphous plastics obtained from green sources because of its natural abundance and the fact that its use does not compete with foodstuff supply. Lignin, as an amorphous polymer, do not show proof of any kind of crystalline structure in X-ray or perhaps electron scattering tests. Amorphous polymers form a sizable group of materials, which include glassy, breakable, and ductile polymers [30, 31]. Lignin is incredibly resistant to chemical substance and enzymatic degradation. Lignin compounds tend to be large, with a molecular size of more than 15,000, and have a three-dimensional structure, which has a common phenylpropane structure, that is, the benzene ring with a tail of three carbons. Lignin contents and structures vary among plant species and among organs within a single plant species. Since the late 19th century, lignin has been the subject of research. Nonetheless, the applications of lignin were restricted because of poor processability, low reactivity, and significant heterogeneity that depend on the plant resource and the extraction techniques utilized. Naturally, lignin is extremely resistant to destruction because of its powerful chemical bonds; it also appears to have many internal H bonds [12, 32-34].

Table 3 Lignin content of *J. curcas*

Organs	Lignin content (%)
Seed coat	49.42 ± 1.11
Seed cake	41.38 ± 1.03
Seed	35.92 ± 3.19
Stem	15.90 ± 0.24
Fruit coat	14.32 ± 0.91
Leaf	9.14 ± 0.32
Squeezed kernel	2.19 ± 0.14
Kernel	1.93 ± 0.30

The presence of diagnostic monomers inside *Jatropha curcas*evidently indicated the existence of lignin. The amount of monomers produced from the stem, fruit coat, seed, seed coat, and seed cake was greater than that from leaf, kernel, and squeezed kernel. In particular, only a small amount of lignin was produced from kernel and squeezed kernel. The seeds have a high lignin content of 35.92 ± 3.19%. The lignin contents of seed coat and kernel were 49.42 ± 1.11% and 1.93 ± 0.30%, respectively. The lignin values in leaf and fresh fruit coating were 9.14 ± 0.32% and 14.32 ± 0.91%, respectively [12, 34, 35].

3.0 EXTRACTION TECHNIQUES

Four main methods have been identified for the extraction of the oil, namely, (i) solvent extraction, (ii) mechanical extraction, (iii) enzymatic extraction, and (iv)microbial extraction. Mechanical pressing and solvent extraction are the most commonly used methods for commercial oil extraction

3.1 Solvent Extraction

Solvent extraction is the technique used to remove one constituent from solid by means of a liquid solvent. Solvent extraction is also called leaching. In solvent extraction, the seeds are clean, de-shelled, and dried at a high temperature of 100–105 °C for 35 min either in the oven or under the sun (three weeks). However, in solvent extraction, only kernels are used as feed. Particle size, type of liquid selected, temperature, and agitation of the solvent are the factors influencing the rate of extraction. Bio-oil was produced from *Jatropha* seed powder using *n*-hexane solvent to extract the oil in the Soxhlet extraction method. Previous studies evaluated the physicochemical properties of Malaysian *Jatropha curcas*oil and concluded that *Jatropha* seed consists of 60% (dry *w/w*) crude oil [15, 16, 28, 36]. Tambunan et al. [10] conducted a study to determine the effects of the mechanical extraction method on the physicochemical properties of the oil extracted. Four different types of samples were used, namely, seeds, kernel, crushed seed, and crushed kernel [17].

The oil was extracted using a specially designed laboratory-scale mechanical extractor, and the yield was calibrated with the Soxhlet apparatus using hexane as a solvent [10, 37]. Crushing of the kernel of *Jatropha* before extracting the oil mechanically, with higher temperature and longer preheating time, will yield more oil [38]. *Jatropha* seed oil was extracted using the Soxhlet apparatus, with trichloroethylene as solvent heated for 6 h. The extracted mixture was cooled, filtered, and dried over anhydrous Na_2SO_4. The filtered mixture was concentrated under vacuum in a rotary evaporator. This extraction technique can yield 97% of oil [38].

Researchers have reported that the oil extracts exhibited good physicochemical properties and could be used as bio-diesel for industrial application because of the detection of the most prominent polyunsaturated OLL (22.94%) and OOL (17.9%) as major triacylglycerol components. Researchers have also concluded that *Jatropha curcas* has significant potential for industrial application, such as the production of bio-lubricant, surface coating, paint, and biodiesel, because of its high oleic and linoleic acid contents.

3.2 Mechanical Extraction

In this type of oil extraction method, either a manual ram press or an engine-driven screw press can be fed with either whole dried seeds or dried kernels or a mixture of both. Notably, the engine-driven screw press can extract 68–80% of the available oil, whereas the manual ram presses can only extract 60–65%. This wide range is due to the fact that seeds can be subjected to different numbers of extractions through the expeller [9, 11, 39-41]. Researchers have reported that segment screw elements of the mechanical screw press is unsuitable for *J. curcas*, which has a large seed. The mechanical strains inside the barrel are high, and the extraction temperature is higher than 80 °C, which causes the dissolution of a large amount of phosphorus in the oil.

3.3 Enzymatic Extraction

This extraction process takes a long time where suitable enzymes are used to extract oil from crushed seeds. The main advantages of this extraction process are that it is environment-friendly and does not produce volatile organic compounds. Shah et al. [42] produced bio-oil from *Jatropha curcas*using aqueous enzymatic oil extraction and determined that the use of alkaline protease yielded better results [43, 44].

3.4 Microbial Extraction

Bacterial cell isolated from paddy crab was used to extract oil from *Jatropha* seed in aqueous form (slurry) without changing the protein structure of the endosperm by inoculation with 1.0 mL of the bacterial starter culture, with antibiotic applied to several samples. The incubation of a *Bacillus pumilus* starter culture with preheated kernel slurry in aqueous media with the initial pH of 5.5 at 37 °C for 6 h liberated 73% *w/w* of the *Jatropha* oil [45]. The advantages of this process are as follows: protein in the residue can be further processed for other applications; no purified enzyme preparation is needed; and the resulting oil can be used for biodiesel production.

3.5 Comparison of the Different Extraction Techniques

Table 4 shows the reaction temperature, reaction pH, time consumption, and oil yield of different extraction methods tested on *Jatropha curcas*. Notably, solvent extraction using *n*-hexane and trichloroethylene in the Soxhlet extraction apparatus results in the highest oil yield, which makes it the most common type. Chemical solvent extraction has a negative environmental effect as a result of wastewater generation, higher specific energy consumption, and higher emissions of volatile organic compounds, and human health effects (working with hazardous and inflammable chemicals). However, *n*-hexane solvent extraction consumes more time compared with the other types. Using aqueous enzymatic oil and hot water extractions significantly reduces these problems. However, solvent extraction is only economical during large-scale production. In the case of mechanical extraction, the segment screw elements of the mechanical screw press is unsuitable for *Jatropha curcas*, which has a large seed. Thus, the extraction temperature should be kept below 80 °C to prevent the dissolution of a large amount of phosphorus in the oil.

Table 4 Reported oil yield percentages for different extraction methods and different reaction parameters [1, 13, 14, 22, 36, 46-49]

Extraction method	Reaction temperature (°C)	Reaction pH	Time consumption (h)	Oil yield (%)
Engine-driven screw press	–	–	–	68–79
Ram press	–	–	–	60–65
n-Hexane oil extraction (Soxhlet) apparatus	–	–	24	95–99
Trichloroethylene oil extraction (Soxhlet) apparatus	–	–	6	97
Aqueous enzymatic oil extraction (hemicellulose or cellulose)	60	7	2	86
Microbial oil extraction (using *B. pumilus* starter culture from paddy crab)	37	5.5	6	73

4.0 INDUSTRIAL APPLICATIONS

Sustainable use of biomass as a renewable source of energy can be an alternative solution to the cost of fossil-based energy and global warming. Plant biomass also produces many different coproducts that have many unexplored uses. The types of coproducts produced depend on the biofuel production and coproduct recovery methods, as well as the source of biomass [3, 12-14, 19].

4.1 Biofuel

Plant biomass produces many different coproducts that have many unexplored uses. The types of coproducts produced depend on the biofuel production and coproduct recovery methods, as well as the source of biomass. Jatropha curcas known as potential source for biofuel production and also energy crop. Jatropha curcas has great potential and valuable as bioenergy feedstock. Jatropha curcas seed cake was also utilized to produce biogas with a high content of methane by means of anaerobic fermentation and gasification. The oil was recognized as suitable for industrial processing and also as energy source. Due to its characteristic as biofuel feedstock, jatropha was very popular and numerous researches were developed [3, 12, 46].

4.2 Biolubricant

An experiment was conducted using jatropha biolubricant, 0%, 20%, 30%, 40% and 50% by volume of Jatropha oil had been blended with lubricant SAE 40. aluminium pins and cast iron disc had been lubricated with Jatropha oil blended bio-lubricant. using viscometer and multi oil analyser tests are able to discovered that 10% of Jatropha oil bio-lubricant gives lowest wear and creates less amounts of heat than others samples, and with above 10% contamination, the wear and lubricating temperature increases considerably[37, 50-52].

4.3 Transformer Oil

Jatropha curcas oil had been discovered to be equivalent to that from the ASTM D Standards, hence the refined Jatropha curcas oil can be utilized in position of the conventional transformer oil because it is biodegradable and safe for the environment due to its low acid content. This is particularly true for utilities in environmentally sensitive areas where spills or leaks can be a threat to marine life [18, 27, 50-53].

4.4 Medicine and Cosmetic

Jatropha seedlings, cuttings, seeds and oil transactions remain confined between seeds collectors, oil extractors and soap makers. Jatropha soap excellent by adding a solution of sodium hydroxide (caustic soda) to jatropha oil. This straightforward Technology has turned soap making into a viable small-scale rural enterprise Suitable to numerous rural areas of developing countries. Jatropha soap is valued being a medicinal soap for treating skin ailments. On the other hand, making jatropha soap could be highly profitable, with 4.7 kg of soap produced from 13 litres of jatropha oil in just five hours .It has been noted that the final consumers of Jatropha soap are individuals with skin diseases and those who find themselves allergic to toilet and perfumed soaps [39, 40, 54].

4.5 Binderless particle board, pulping and paper making industries

Pulp and paper industries are one of the most vital industries of the developed and developing nation's economy. Jatropha curcas one the most abundant source of papermaking fibre, because of the presence of various compounds (lignin and extractives).Also, presence of diagnostic monomers inside Jatropha curcas evidently indicated the existence of lignin, Lignin obtained as a by-product of the binderless particle board ,pulp and paper industry plays a vital role in the industries been one of the main sources of papermaking and binderless particle board fibre [33, 55-59].

4.6 Biodiesel

Among the numerous non-edible sources, Jatropha Curcas is recognized as potential biodiesel source. Jatropha curcas seed oil extracts exhibits good physicochemical properties. The oil extracts contains major TAG of monounsaturated OLL, POL, SLL, PLL, OOL, OOO and POP followed by LLL. Jatropha curcas seed oil can be classified as unsaturated oil with an unsaturated fat level of 80.42%. The high amount of monounsaturated fatty acid can find an application as a biodiesel feed stock and industrial application.

JCL seed cake was utilized to produce biogas with a high content of methane by means of anaerobic fermentation and gasification [1, 13, 14, 22, 36, 46-49].

4.7 Fertilizer

Jatropha curcas seed cake as well as other by-products of JCL, such as the fruit coats and seed hulls can also be used as organic fertilizers. The results of the experiment have shown that fertilization to jatropha plantation with jatropha cake was very effective in improving yield significantly. The seed yield increased significantly with increasing dose of cake up to the maximum level of 3 tonnes per hectare. The encouraging results proves the use of jatropha cake as a nutrient rich manure in jatropha plantation itself by ploughing it back into the soil. This will help to increase productivity of Jatropha curcas on wasteland, and probably should also improve the soil fertility[12, 60].

4.8 Surface coating

The presence of unsaturated triglyceride in the Jatropha curcas seed significantly increased the scratch resistance, glossiness and hardness of the EJO oligomer green coating. The jatropha seed oil-based resins could potentially be used as eco-friendly resins in surface coatings, particularly in overprint varnish applications [36, 61, 62].

5.0 CONCLUSION

This study justifies the potential of *Jatropha curcas* seed oil and its uses in cosmetic production through the extraction of its seed oil. The presence of a high amount of polyunsaturated fatty acids (linoleic acid) in *Jatropha curcas* seed oil makes it potentially useful for oleochemical applications, such as surface coating industries and bio-lubricant-based oil applications. By contrast, the presence of a high amount of monounsaturated fatty acid in *Jatropha curcas* seed oil makes it potentially useful for biodiesel feed applications. Refined *Jatropha curcas* oil can also be safely used in place of the conventional transformer oil because it is environment-friendly and is easily biodegradable due to its low acid content. *Jatropha curcas* oil is used as cutting fluid that prevents warpage of parts because of its cooling property. Also, basic data for making pulp and paper, particle boards, and wood pellets from *Jatropha curcas* wood have also been provided for the wood and paper making industries. This study recommends:

i. Solvent extraction using *n*-hexane and trichloroethylene in the Soxhlet extraction apparatus results in the highest oil yield, which makes it the most common type although chemical solvent extraction has negative environmental effects. Using aqueous enzymatic oil and hot water extractions significantly reduces the environmental problems. However, solvent extraction is only economical during large-scale production.

ii. Crushing the seed before extracting the oil mechanically will ensure higher oil yield and higher extraction efficiency. Higher temperature and longer preheating time also increase the oil yield and free fatty acid value.

iii. Improved design of equipment for extracting oil from the seeds with optimum quantity and quality is needed for industrial production. Industries and the government have an active role to play. Governmental and educational institutions have to play its role to obtain a better processing yield of *Jatropha curcasseed* oil.

iv. Considering the cultivation of this species in large-scale farms, more studies are required and more facts regarding the actual and potential markets for all its products are needed.

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