

Jatropha: An Alternative Substitute to Fossil Fuel¹

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Abstract

Jatropha curcas L. is a non-food bioenergy plant that is known for the production of biofuel. *Jatropha* can be considered a second-generation biofuel plant that may provide a portion of the fuel supply. *Jatropha* is a tropical plant and can be grown in low to high rainfall and diverse soil types, but the plant is susceptible to freezes. The plant produces seeds containing inedible oil that can be converted to biodiesel, which can be used in the transportation and energy sectors. The detoxified cake by-product from oil extraction can be used for fish and animal feed, biogas, or as an organic fertilizer. The crop can be mechanically harvested, and oil yields are comparable or higher than soybean and rape seed without genetic improvement. *Jatropha* produces renewable energy in the form of biodiesel, which emits 80% less CO₂, 100% lower SO₂, and has a higher flash point than fossil diesel fuel. The *Jatropha* biodiesel industry currently is relatively minor; therefore, as it grows to a larger scale and the infrastructure is developed, the costs of producing and marketing *Jatropha* biodiesel may decline in the future.

Introduction

Jatropha curcas L. belongs to the Euphorbiaceae family. *Jatropha* is a multipurpose plant that originated in Central America but can now be found throughout the tropics, including Africa and Asia (Openshaw 2000). As a second-generation (non-food supply) biofuel crop, it can affordably and sustainably help to provide a portion of the current fuel supply with minimal environmental impact. The goal of

second-generation biofuel is to increase the biofuel supply with crops such as *Jatropha*, castor (*Ricinus communis*), and *Camelina* (*Camelina sativa*). *Jatropha* yields a considerable amount of inedible oil that can be converted to biodiesel. The oil can be used as a direct replacement for fuel in engines and machines, and it has other industrial and commercial uses as well (Cerrate et al. 2006; Ndong et al. 2009). Additionally, different parts of *Jatropha* have medicinal value, such as anticancer properties (Duke 1983). Roots and leaves can be used to make antibiotics and products for the treatment of skin diseases (Henning 2002). Being rich in nitrogen (N), the seed cake can be an excellent plant nutrient source if detoxified (Makkar et al. 1998).

Presently, some countries are producing *Jatropha* oil to supplement the fuel requirements for lamps, cooking, and small diesel engines. *Jatropha* is being cultivated in 32 countries around the world, including India, Mali, Mexico, Sri Lanka, Nepal, Cambodia, South Africa, Tunisia, China, Bangladesh, Egypt, and the United States (Figure 1). *Jatropha* oil has successfully been used in small diesel engines in India, Brazil, Madagascar, Thailand, Vietnam, China, Indonesia, and Myanmar (Heller 1996). South Florida soils are suitable for cultivation of *Jatropha*, but the tree's susceptibility to occasional freezing temperatures makes South Florida unsuitable for commercial cultivation. However, if freeze protection is provided, plants can be preserved.

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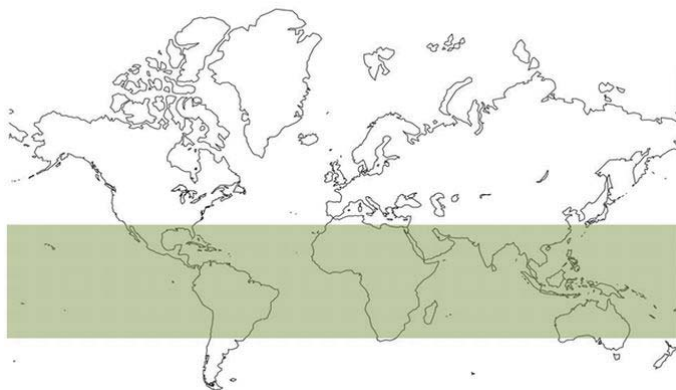


Figure 1. Cultivation limits of *Jatropha curcas* (Source: Brittain and Litaladio 2010)

Plant Morphology

Jatropha is a small tree with smooth gray bark. The bark discharges a white, watery latex when cut. Generally, the tree can grow between 6.0 and 18.0 ft (1.8–5.5 m) in height, but it can grow to 30.0 ft (9.2 m) given favorable conditions.

Leaves: There is tremendous variability in morphology. In general, *Jatropha* leaves are green to pale green, alternate to subopposite, and three- to five-lobed with a spiral phyllotaxis.

Flowers: The petiole length ranges from 0.24 to 0.90 inches (6.1–23.1 mm). The inflorescence can be formed in the leaf axil. Flowers are formed terminally and individually, and female flowers are slightly larger during the warmer months. However, there is variation here as well. Furthermore, it is important to note the ratio of male to female flowers. The plant is monoecious and also presents hermaphroditic flowers occasionally.

Fruits: In the winter, plants lose their leaves and do not produce fruits; most fruit production is concentrated from midsummer to late fall with variations in production peaks; some plants have two or three harvests and some produce continuously through the season. In Florida, there is variability in fruit production. Three bivalved cocci are formed after the seeds mature and the fleshy exocarp dries (Figure 2). Fruits are produced continuously from midsummer to late fall, which may be an obstacle to mechanical harvest and increase harvest costs because of the need for multiple harvests.

Seeds: The seeds become mature when the capsule changes from green to yellow after 2–4 months. The seeds contain 21% saturated fatty acids and 79% unsaturated fatty acids (Gubitz et al. 1999), and they yield 25%–40% oil by weight (Deng et al. 2010; Heller 1996) (Figure 3). Additionally, the seeds contain other chemical compounds, such as

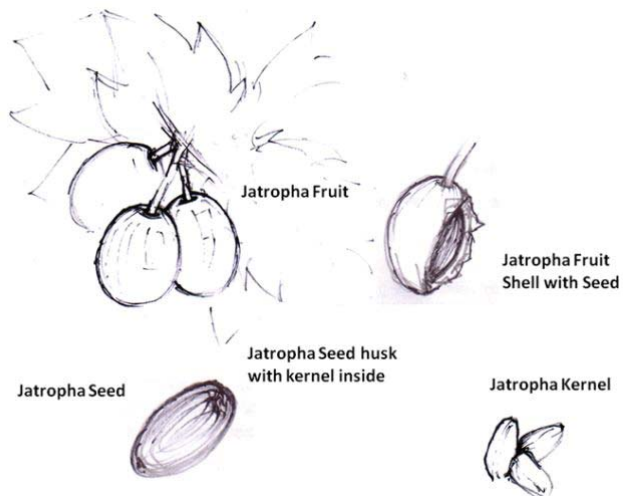


Figure 2. Fruit composition of *Jatropha curcas* (Source: Nahar 2011)

saccharose, raffinose, stachyose, glucose, fructose, galactose, and protein. The oil is largely made up of oleic and linoleic acids (List and Horhammer 1979). *Jatropha* also contains curcasin, arachidic, linoleic, myristic, oleic, palmitic, and stearic acids and curcun (Perry 1980). Curcun and phorbol ester are toxic compounds contained in the *Jatropha* meal. However, the meal can be suitable for animal feed after a detoxification process (Gaur et al. 2011).

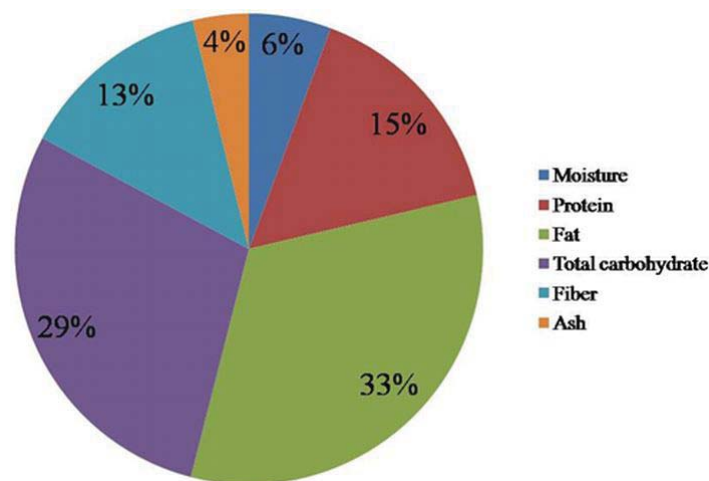


Figure 3. Chemical elemental analysis of a *Jatropha curcas* seed (Source: Adapted from Duke and Atchley 1984)

Crop Adaptability

Climate: *Jatropha* is a highly adaptable species and is especially tolerant of severe heat. This plant thrives in warmer weather. The plant is susceptible to freeze damage but can tolerate a light frost of relatively short duration. *Jatropha* can survive light freezes using overhead high-volume irrigation. The plant drops its leaves when cold. Older trees can withstand lower temperatures than younger trees. Black frost (internal freezing of vegetation) can kill young plants and severely damage older plants. The tree can survive in

occasional flooding. In past flooding instances in Florida, heavy rains and water-logged soils caused defoliation and promoted the development of *Pythium* root rot, which severely injured or killed many plants.

Soil type and quality: The plant thrives on different soil types, including infertile, gravelly, sandy, and/or saline soils (Dagar et al. 2006). *Jatropha* can also thrive on the poorest stony soil. The plant does not require arable land and can be grown in marginal dry soils, such as along railway lines, roads and highways, river embankments, canals, streams, crop boundaries, and coastal lines, as well as in hilly areas, but yield will be lower than crops grown in arable land. It can grow in pH ranging from 5.5 to 9.0 (Foidl et al. 1996). Once the root penetrates deeper into the soil, *Jatropha* can tolerate even more acidic or alkaline soil, but yield will be lower than optimal pH ranges. In projects around the world, *Jatropha* plantations have failed because plants were planted in poor soil conditions and returned very low or no yields. It is important to understand that plants can adapt to and grow under poor soil conditions, but for commercial yields, proper crop management, such as irrigation and fertilization, is needed.

Biophysical limits: *Jatropha* mainly grows at altitudes of 0–6,000 ft (0–2,000 m) where optimal temperature ranges from 68°F to 104°F (20°C–40°C); however, temperatures lower than 50°F (10°C) and higher than 122°F (50°C) are acceptable for short periods of time (Misra and Misra 2010).

Cultural Practices

Germination: Germination normally takes 7–10 days with optimum moisture conditions. The shell splits, the radicle emerges, and four peripheral roots are formed.

Propagation method: Several propagation methods can be used, such as direct seeding, transplanting, direct planting (cutting), or tissue culture (Freitas and Barjona 1906). Direct planting by cutting decreased the time of production as compared to direct seeding or transplanting (Table 1). However, it does not produce a good tap root, which is why this is not the method used by most growers. Propagation through seed (sexual propagation) leads to genetic variability in terms of growth, biomass, seed yield, and oil content. This is because there is no certified seed production in *Jatropha*. Low seed viability and poor germination also limit seed propagation. Vegetative propagation has been achieved by stem cutting, grafting, and budding as well as by air layering techniques. The cuttings should be taken preferably from juvenile plants and treated with 200 mcg.l⁻¹

of rooting hormone indole butyric acid (IBA) to ensure the highest level of rooting for the cutting (Noor Camellia et al. 2009). The optimal stem for cutting is 0.08 inches (2.0 mm) in diameter and 1.0 ft (30.4 cm) in length. The stem pieces can be cut from the mother plant and planted at any time of the year. If it is planted during a dry period, irrigation is required.

Plant population: Plant spacing of 5.9 by 5.9 ft or 8.8 by 8.8 ft (1.8 by 1.8 m or 2.7 by 2.7 m, respectively) is acceptable with plant densities of 1,012 plants.acre⁻¹ (2,500 plants.ha⁻¹). Distance of 8.8 by 8.8 ft (2.7 by 2.7 m) may be more desirable for commercial cultivation because wider spacing is reported to increase crop yield by increasing fruit size (De Avila 1949). However, spacing depends on the harvest method; mechanical harvest in large-scale commercial plantations may require more open spacing. Manual harvesting, which is applicable to smaller plantations (Central and South America, Africa and Asia), is the best method for sustainable production and generating jobs in developing countries.

Irrigation: The plant is adapted to dry soils. *Jatropha* plants can survive from air humidity when rainfall is as low as 10.0 inches (254 mm) per year. In Florida, unirrigated *Jatropha* failed to reach 2.5 ft (75 cm) after 1 year. Rainfall of 12.0–40.0 inches (305–1,016 mm) produces optimal yields. *Jatropha* can also stand for long periods without water (as long as 2 years) and regrow when rains return. The average water consumption rate of *Jatropha* is 1 L/plant/day throughout the growing season with high-quality seeds (PSO 2010).

Fertilization: *Jatropha* is adapted to low soil fertility. In general, fertilized *Jatropha* trees provide higher yields than trees without fertilizer (Mohapatra and Panda 2011; Moore et al. 2011). Higher yields can be obtained on poor-quality soils if fertilizers are applied containing N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) (Table 2). After transplant and establishment, cow manure and N-P-K fertilizer can be applied annually (PSO 2010).

Weed control: Depending on the field conditions and season, weeding can be performed four times per year by soil surface plowing or by applying herbicides, such as oxyfluorfen or pendimethalin (Rocha 2010).

Pruning: Plants should be pruned once a year. The tree needs side shoots for maximum sprouting, flowers, and seed production. From December to January, the top of the plants at 0.80 ft (25 cm) tall or higher need to be topped

while keeping 8–12 side branches for more fruit production (Gour 2006). To facilitate harvesting, it is suggested to keep the tree to a height of approximately 6.6 ft (2 m) (Reddy and Naole 2009). In South Florida, the trees were never pruned and produced sufficient branches, although this may seem contrary to what literature reports. Trees were pruned after 2 years only to maintain a manageable size.

Intercropping: According to the topography, soil profile, and prevailing agro-climatic conditions in an area, *Jatropha* trees can be combined with other suitable species, such as with agricultural, horticultural, herbal, pastoral, and/or silvicultural cropping systems. Without cutting the lateral roots of *Jatropha*, intercropping with crops such as maize (*Zea mays* L.), indigo (*Indigofera tinctoria* L.), lentil (*Lens culinaris* M.), wheat (*Triticum aestivum* L.), coffee (*Coffea arabica* L.), sugarcane (*Saccharum officinarum* L.), castor oil (*Ricinus communis* L.), medicinal plants, fruits, grasses, tubers, and vegetables can be a source of extra earnings for farmers (Singh et al. 2007).

Harvesting: *Jatropha* takes 4–5 years to be highly productive. Flowering depends on location and agro-climatic conditions. Generally, cloned *Jatropha* seedlings produce flowers in the first 4 months. By cloning the strongest and highest-yielding plants, the clones inherit the characteristics of the parent plants. When *Jatropha* fruits are mature, they can be mechanically harvested using equipment such as the Korvan 9240 (Figure 4; Oxbo International Corporation 2011). Mechanical harvesting provides several benefits, such as selective and continuous harvesting, cost control, labor reduction, efficiency and reliability, and the ability to harvest on demand. However, it can damage flowers that are still in the plant and harvests both mature and immature fruits. Flower and fruit synchronicity is an issue that is being addressed to solve some of these problems.



Figure 4. *Jatropha curcas* mechanical harvester KORVAN 9240 (Source: Oxbo International Corporation 2011)

Crop yield: None of the *Jatropha* species have been properly domesticated. Therefore, the productivity of individual trees can be variable, and the long-term impact on large-scale production and uses is currently unknown. Estimates of *Jatropha* seed yield vary widely because of a lack of research, genetic diversity, and the range of environmental conditions in which the crop can be grown. The

tree can begin production 9–12 months after germination, but optimal yields can be obtained after 4–5 years. Seed production ranges from about 0.13 to 4.86 t.acre⁻¹ (0.3–10.9 t.ha⁻¹) per year (Openshaw 2000). Heller (1996) reported yield variability of 0.09–7.2 t.acre⁻¹ (0.2–16.1 t.ha⁻¹) per year, probably because of low and high rainfall areas. However, 4.4–5.5 t.acre⁻¹ (9.8–12.3 t.ha⁻¹) of dry seed is a reasonable yield estimate for an adequately managed plantation with favorable environmental conditions (Achten et al. 2008). *Jatropha* can be a competitive feedstock when compared to soybeans and rape seed, which produce lower oil yields than *Jatropha* (U.S. DOE 2010; Figure 5). The seed kernel contains predominantly crude fat (oil) and protein, while the seed coat contains mainly fiber (Brittaine and Litaladio 2010). The products of the harvested *Jatropha* fruits and their fractions by weight are shown in Figure 6.

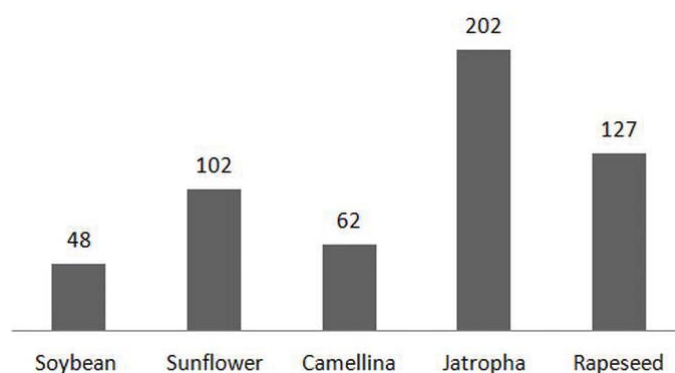


Figure 5. Comparison of oil yields from different biomass feedstock (Source: U.S. DOE 2010)

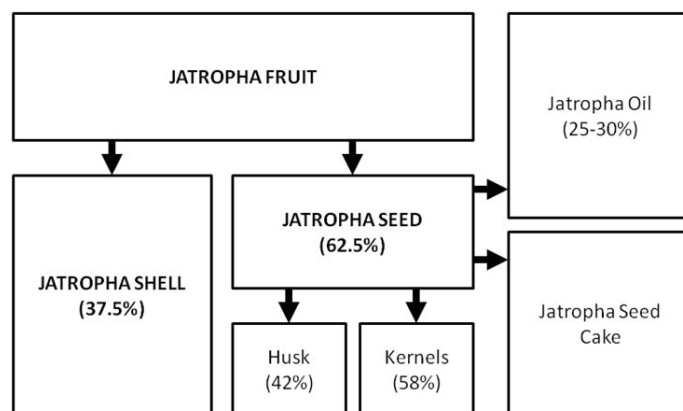


Figure 6. Fruit composition percentage of *Jatropha curcas* (Source: Abreu 2008)

Crop Uses

The oil is mainly used as biodiesel for energy. The cake can be used for fish or animal feed (if detoxified), biomass feedstock to power electricity plants, or as biogas or high-quality organic fertilizer (Figure 7) (Achten et al. 2008; Ghosh et al. 2007; Patolia et al. 2007; Wani et al. 2006).

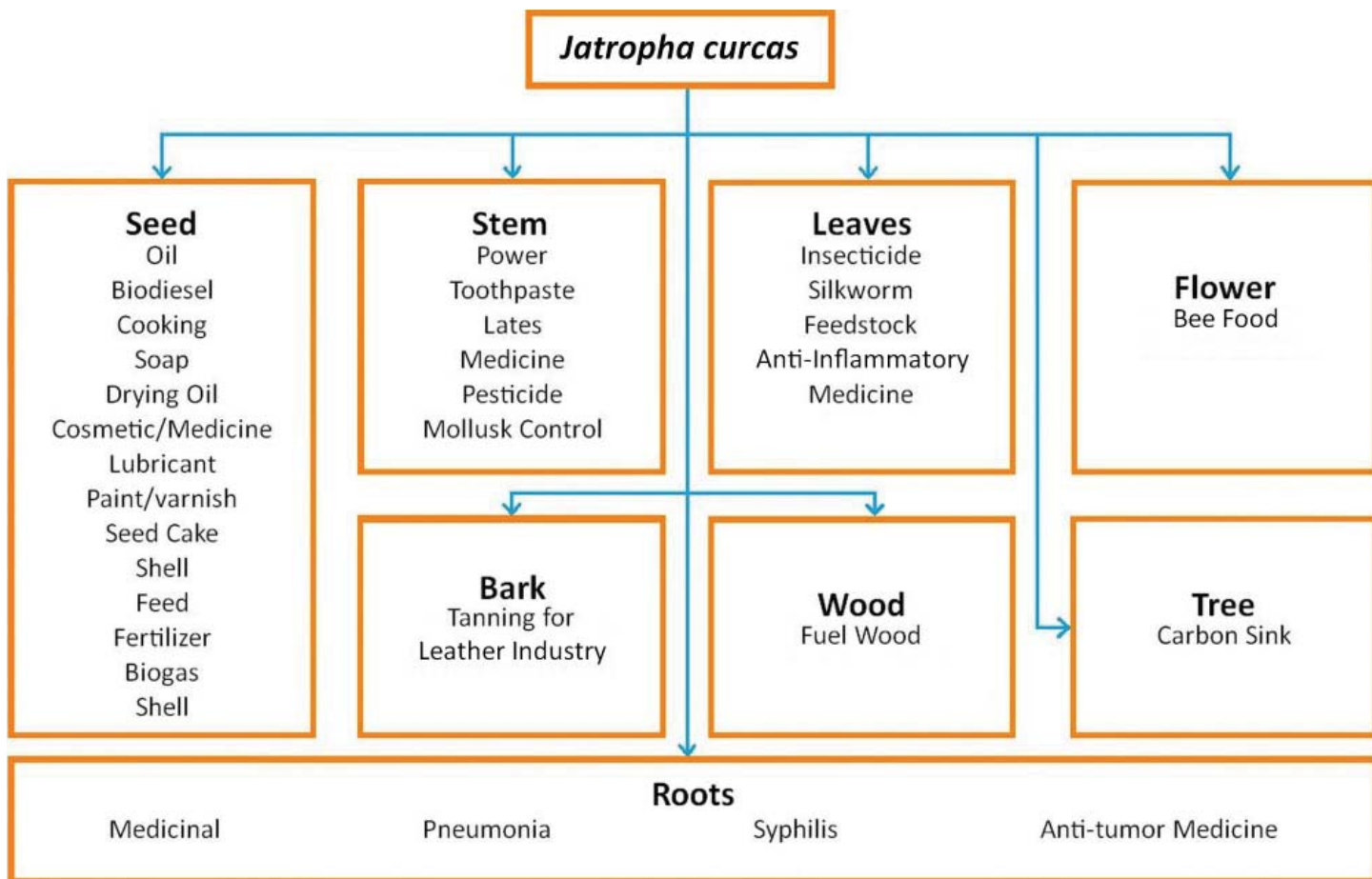


Figure 7. Uses of *Jatropha curcas* (Source: Adapted from Heller 1996; Openshaw 2000)

It can also be used as a bio-pesticide and for medicinal purposes (Heller 1996; Figure 7).

***Jatropha* biodiesel production:** When *Jatropha* seeds are crushed, the resulting oil can be processed to produce a high-quality biodiesel that can be used in a standard diesel engine. Oil extracting and refining equipment is available in the international market at a price of approximately \$30,000. An old mustard (*Brassica juncea* L. Czern) expeller, which is a machine to extract oil from oil seed plants,

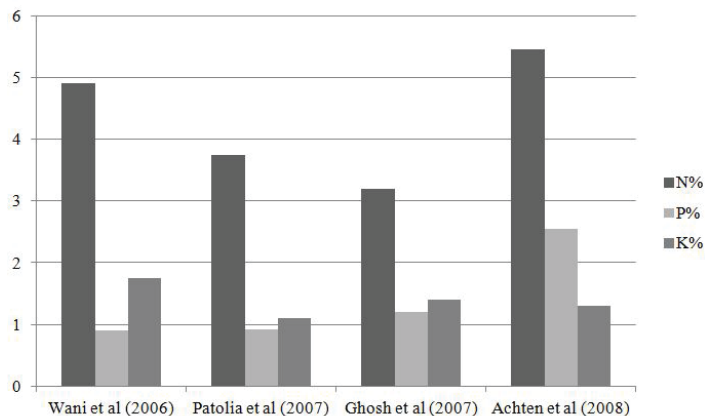


Figure 8. Percentage of nitrogen, phosphorus, and potassium in *Jatropha curcas* seed cake

can be modified and used for *Jatropha* oil extraction. Small-scale hand-operated expellers can extract 0.26 gal (1 L) of oil per 11.0–12.1 lb (5.0–5.50 kg) of seed, while engine-driven screw presses can produce 0.26 gal (1.0 L) of oil from 4.0 lb (1.8 kg) dried seed (Henning 2002; Jongschaap et al. 2007). Manually operated small units that can be manufactured locally are also available. Additionally, various alternative methods, such as ram, hole cylinder, and strainer type presses, can be used for processing seed.

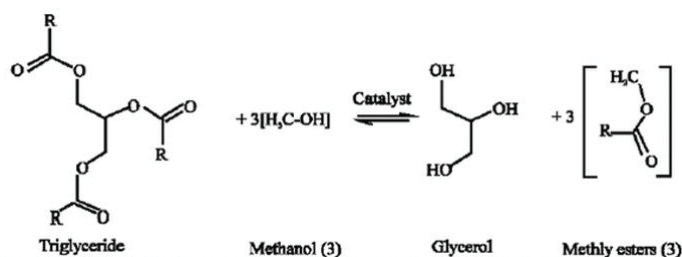
There are several forms of biofuel, often manufactured using sedimentation, centrifugation, and filtration. The fats and oils are turned into esters while separating the glycerin. At the end of the process, the glycerin settles and the biofuel floats. The process through which the glycerin is separated from the biodiesel is known as transesterification. Glycerin is another by-product from *Jatropha* oil processing that can add value to the crop. Transesterification is a simple chemical reaction that neutralizes the free fatty acids present in any fatty substances in *Jatropha*. A chemical exchange takes place between the alkoxy groups of an ester compound by an alcohol. Usually, methanol and ethanol alcohol are used for the purpose. The reaction occurs by the presence of a catalyst, usually sodium hydroxide (NaOH) or caustic soda

and potassium hydroxide (KOH), which forms fatty esters (e.g., methyl or ethyl esters), commonly known as biodiesel. It takes approximately 10% of methyl alcohol by weight of the fatty substance to start the transesterification process (Ibeto et al. 2011). The production schematic is illustrated in Figure 9 (Nahar and Sunny 2011). The transesterification process using methanol can be expressed by the simplified equation shown below:

Oil or Fat (Triglycerides) + Methanol = Methyl Ester + Glycerol

$$3.52 \text{ oz} + 0.37 \text{ oz} = 3.54 \text{ oz} + 0.36 \text{ oz}$$

$$100 \text{ g} + 10.75 \text{ g} = 100.45 \text{ g} + 10.3 \text{ g}$$



Some of the chemicals that are used in the manufacturing of biodiesels are ethanol or methanol that bring into use methyl esters. Methanol is derived from fossil fuels, and ethanol is derived from plants. In the transesterification stage, the by-product is glycerol, which is approximately 10% of the raw oil by weight. Glycerol yield can be less than 10% of the raw oil, and a greater conversion to glycerol means greater revenue, assuming that the price of the glycerol remains constant. Revenues generated from coproducts like glycerol can reduce the net marginal cost of biodiesel production (Brittaine and Lutaladio 2010).

The benefits of biodiesel: Diesel substitutes from renewable sources such as biodiesel have similar properties to diesel fuel. These substitute fuels contain less sulfur (S) content and may be used in diesel engines without major engine modifications (Ramesh et al. 2006). The properties of *Jatropha* biodiesel are shown in Table 3, and the comparison between *Jatropha* biodiesel, petroleum-based diesel, and a mixture of the two is shown in Table 4.

Characteristics of *Jatropha* oil: *Jatropha* oil has similar characteristics to fossil diesel fuel, and it can be directly used in the diesel engines of buses, trucks, tractors, and other diesel engines. The high stability in low temperatures makes it very attractive for use in jet fuels, and this has been tested successfully. Table 5 shows the characteristics of *Jatropha* oil in comparison with fossil diesel. *Jatropha* oil

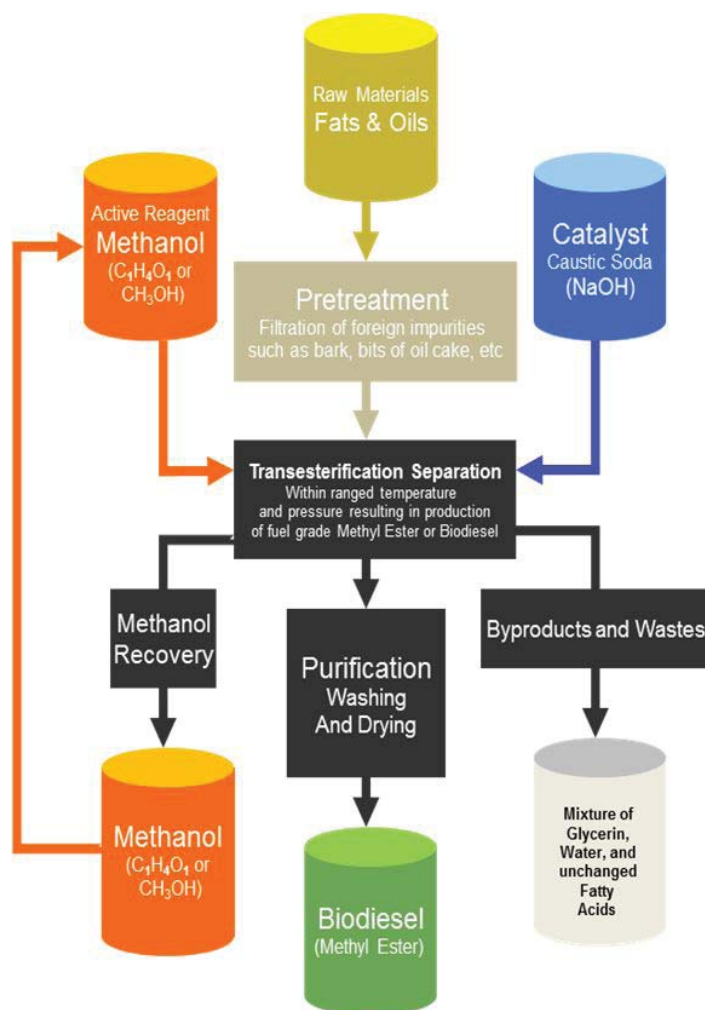


Figure 9. *Jatropha curcas* biodiesel production flow chart (Source: Nahar and Sunny 2011)

causes less air pollution during engine operation because it contains lower S concentration than petroleum diesel. *Jatropha* is also safer to store than petroleum diesel since it has a higher flash point. In addition, *Jatropha* oil viscosity is slightly lower than the fossil diesel, which allows smooth flow of the oil through the injector (Brittaine and Lutaladio 2010).

Environmental impact: As a perennial shrub, *Jatropha* can sequester carbon (C). A full-grown tree absorbs around 17.4 lb (7.9 kg) of CO₂ every year (PSO 2010). If the plant density is 1,012 plants.acre⁻¹ (2,500 plants.ha⁻¹), it is possible to acquire an 8.7 t.acre⁻¹ (18.1 t.ha⁻¹) of greenhouse gas sequestration per year. *Jatropha* produces renewable energy in the form of biodiesel, which emits 80% less CO₂ and 100% less SO₂ than fossil diesel (Tiwari et al. 2007). Biodiesel from food crops such as corn can cause food shortages. For biodiesel, *Jatropha* yields similar fuel per acre (ha) than soybean or other energy crops (Chawla 2010).

Production cost: The cost of plantation in the United States has been estimated to be around \$1,000/acre⁻¹ (\$550/ha⁻¹). *Jatropha* plantation includes site preparation, soil preparation, fertilizer and manure application, planting, irrigating, weeding, plant protection, and maintenance for a year (Meng 2009).

An integrated *Jatropha* biodiesel plantation has three stages: sowing of seeds, producing oil from the seeds, and finally converting raw oil to biodiesel through transesterification. The biodiesel industry is relatively small, so as the industry expands with increased infrastructure, the costs of producing and marketing biodiesel may decline. New cost-saving technologies will likely be developed to help producers use energy more efficiently and increase conversion yields. The supply of soybeans, rape seeds, and other feedstock available for biodiesel production will be limited by increased food and land demand. The key to the future of biodiesel is finding inexpensive feedstock that can be grown by farmers on marginal agricultural land without adverse environmental consequences, and *Jatropha* may be one of these alternative crops. If *Jatropha* proves to be a promising biofuel, this tree species may emerge as a viable alternative to petroleum diesel. In Florida, breeding and genetic improvement programs initiated at the University of Florida's Tropical Research and Education Center (UF/TREC) may provide new hybrid cultivars with several characteristics of interest, including cold tolerance, high oil content in seeds, and low toxicity, which are the key for expanding cultivation areas in Florida (Crane et al. 2010).

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Table 1. Reproduction, propagation methods, and stages of development for *Jatropha curcas*

Reproduction	Propagation methods	Stage of development	Duration (month)
Sexual	Seed	Transplant and flowering	12
Asexual	Cutting	Flowering	3
		Fruiting	4
		Harvesting	5–6

Table 2. Cow manure and nutrient requirements (N-P-K) of *Jatropha curcas*

Source of nutrients	Rate (lb.acre ⁻¹)	Rate (kg.ha ⁻¹)
Cow manure	2,679	3,000
N	192	215
P ₂ O ₅	53	60
K ₂ O	21	24

Table 3. Physical and chemical properties of fuel-grade biodiesel

Properties	Characteristics
Ignition point °F	266
Specific gravity (dimensionless)	0.85–0.90
Volatility by volume (%)	< 2
Stability	Very high
Solubility in water	Insoluble
Atomic weight (amu)	292
Appearance and odor	Pale yellow liquid with mild fruity odor
Chemical formula	C ₁₁ H ₂₀ O ₂ ~C ₁₉ H ₃₈ O ₂

Source: Quoreshi 2007

Table 4. Comparison of *Jatropha curcas* biodiesel with petroleum-based diesel

Properties	<i>Jatropha</i> biodiesel	Mixture*	Petroleum diesel
Fuel Consumption, g/kw/h	629.7	1,298.0	784.0
Mass of fuel, lb.h ⁻¹	1.36	0.97	1.56
Brake thermal efficiency, %	24.09	10.80	11.76
Mass of air, lb.h ⁻¹	12.17	18.71	17.50
Air fuel ratio	8.90	19.30	31.15
Exhaust % of CO ₂	1.33	5.00	9.00
Exhaust % of O ₂	17.67	8.00	5.00
Exhaust % of CO	0.00	1.00	1.00

*50% *Jatropha curcas* biodiesel and 50% petroleum diesel
Source: Rahman et al. 2010

Table 5. Characteristics of *Jatropha curcas* biodiesel and comparison with diesel

Characteristic/Variable	<i>Jatropha</i> biodiesel	European standard petroleum diesel
Density at 68°F (kg.m ³)	869.5	859.7–899.4
Viscosity at 40°C (cSt)	4.2	3.5–5.0
Flash point (°C)	191	101
Cetane number	58–62	> 51

Source: Francis et al. 2005