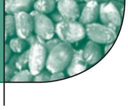

CHAPTER 1

Introduction

Since the surge of interest in renewable-energy alternatives to liquid fossil fuels hit in 2004/5, the possibility of growing *Jatropha curcas* L. for the purpose of producing biofuel has attracted the attention of investors and policy-makers worldwide. The seeds of jatropha contain non-edible oil with properties that are well suited for the production of biodiesel.

Although optimum ecological conditions for jatropha production are in the warm subhumid tropics and subtropics, jatropha's ability to grow in dry areas on degraded soils that are marginally suited for agriculture makes it especially attractive. In addition, jatropha can be used as a living fence to keep out livestock, control soil erosion and improve water infiltration. The waste products from jatropha biodiesel production can be used as fertilizer and for producing biogas, and the jatropha seedcake can potentially be used for livestock feed.

Although there have been increasing investments and policy decisions concerning the use of jatropha as an oil crop, they have been based on little evidence-based information. There are many knowledge gaps concerning the best production practices and the potential benefits and risks to the environment. Equally troubling is that the plant is in an early stage of domestication with very few improved varieties. Identifying the true potential of jatropha requires separating the evidence from the hyped claims and half-truths.

This publication reviews the information currently available on jatropha as a bioenergy crop, starting with the papers presented to the April 2008 IFAD/FAO International Consultation on Pro-Poor Jatropha Development held in Rome, Italy (IFAD 2008). This information has been supplemented by consulting various reports, conference papers, and both published and unpublished scientific papers.

Based on the output of the International Consultation, the aim of this report is to identify the jatropha production systems that are most sustainable and viable and that can contribute to rural development and alleviate poverty. It also points out the critical areas of needed research, trusting that this information will be useful for decision-makers as well as for those actively involved in jatropha production.

This introductory chapter offers general background on liquid biofuels, energy poverty and global jatropha production trends.

BIOFUELS – AN OVERVIEW

Bioenergy and biofuels

Bioenergy is a renewable, non-fossil energy obtained from the combustion of biomass, most often in the form of fuelwood, biogas or liquid biofuel. Liquid biofuels can be bioethanol, biodiesel or straight vegetable oil. While bioethanol (ethyl alcohol) is a chemical compound, biodiesel is a mixture of compounds that varies in physical properties according to the feedstock used to produce it. Liquid biofuels can replace petrol and diesel for transport use and can be used in stationary engines to generate electricity, pump water and mill food grains as well as for cooking and lighting.[1]

First, second and third generation biofuels

Levels of technological development for biofuels are defined as first, second and third generation (CGIAR 2008). First generation biofuels, which are the fuels now in common use, derive mainly from food crops by utilizing conventional technology. The important biofuel crops are maize, sugar cane and sugar beet for the extraction of sugars to produce

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[1] The prospective risks and opportunities of these fuels and their impacts on agriculture and food security are described in the *2008 FAO State of Food and Agriculture* (SOFA).

bioethanol, and soybean, rapeseed and oil palm for the extraction of oil to produce biodiesel.

Technologies for second and third generation biofuels remain under development. They offer the prospect of producing biofuels from non-food sources such as fast-growing trees, grasses and carbon-rich waste materials. These future technologies will also have the capability of converting algae and bacteria into oils that can replace petroleum fuels.

The need to optimize resources and minimize waste also has prompted research into the production of higher value chemicals and commodities as by-products of biofuel feedstock processing. Brazil's sugarcane industry has adopted this bio-refinery concept, using the waste bagasse left after sucrose extraction as a fuel to produce electricity.

Bioethanol and biodiesel

Bioethanol: Sucrose is extracted from the plant stem or tuber of sugar-rich crops, fermented and then distilled to produce bioethanol (alcohol). Crops rich in starch, such as maize and cassava, need a pre-treatment to convert the starch into fermentable sugars. Bioethanol is commonly blended with petrol in proportions of up to 5 percent (E5) for which no engine modification is required.

Biodiesel: Trees, shrubs and herbaceous oilseed plants may be used for the production of biodiesel through trans-esterification – a process by which alcohol is added to vegetable oil in the presence of a catalyst. The seeds of oil-rich plants are hulled and pressed to extract the oil which is then filtered. Methanol is added to the raw vegetable oil, using sodium (or potassium) hydroxide as the catalyst. The product is a vegetable oil methyl ester (VOME) or, in the case of jatropha, jatropha methyl ester (JME). Biodiesel has very similar properties to petroleum diesel. The main by-product of this process is glycerine, which also has diverse commercial uses. Biodiesel may be directly substituted for petroleum diesel (gas oil) in blends of up to 5 percent (B5) without engine modification.

Figure 1 illustrates the basic processes of converting plants to transport fuels.

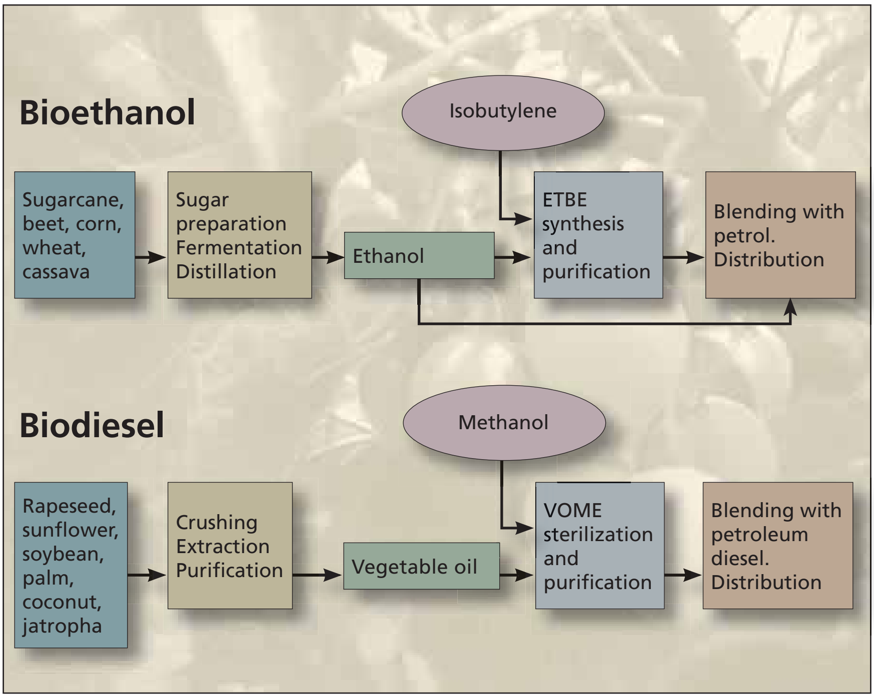


FIGURE 1: **Bioethanol and biodiesel production processes**

Straight vegetable oil

Extracted and filtered vegetable oil can be used directly as a fuel in suitable diesel engines without undergoing the trans-esterification process (Achten *et al.*, 2008). While there are issues with poor performance, increased maintenance, reduced engine life and engine manufacturers who void warranties if vegetable oils are used, there is now considerable experience with using straight vegetable oil in suitably modified diesel engines (de Jongh and Adriaans, 2007; Cloin, 2007).

GROWTH DRIVERS OF BIOFUELS

Growth of the biofuel industry is being driven by government policies in three main areas. This includes policies aimed at mitigating climate change, improving energy security and using biofuel production as a strategy to support rural development.

Mandates and targets for inclusion of biofuels in petrol and diesel, together with subsidies and border protection in the form of import tariffs and quotas, are the means by which governments provide the impetus to drive biofuel growth. The United States of America (USA) leads in production-related subsidies while other countries, including the European Union (EU) and Brazil, largely use tax exemptions as the policy instrument for the promotion of biofuels.

Climate change

The need to slow or reverse global warming is now widely accepted. This requires reduction of greenhouse gas (GHG) emissions, especially reduction of carbon dioxide emissions. Using cultivated and non-domesticated plants for energy needs instead of fossilized plant remains such as mineral oil and coal reduces the net addition of CO_2 to the atmosphere. In addition, biodiesel produces fewer particulates, hydrocarbons, nitrogen oxides and sulphur dioxides than mineral diesel and therefore reduces combustion and vehicle exhaust pollutants that are harmful to human health.

Energy security

The search for renewable energy is being driven by volatile crude oil prices and the perceived threat to national security of over-dependence on foreign supplies. Crude oil prices are likely to increase over the long term as fossil reserves diminish and global demand increases, particularly in the newly emerging economies of Asia and Latin America.

However, the potential of biofuels to enhance energy security is limited. Globally, the huge volume of biofuels required to substitute for fossil fuels is beyond the capacity of agriculture with present day technology. For example in 2006/7, the USA used 20 percent of its maize harvest for ethanol production, which replaced only three percent of its petrol consumption (World Bank, 2008). More significant displacement of fossil fuels will be likely with second and third generation biofuels (SOFA, 2008).

Rural development

Government policy in support of rural development, the third main driver of biofuel growth, has been enabled by the large demand for biofuel feedstocks and the import substitution potential of biofuels. In OECD countries, biofuels are seen as a new market opportunity due to their ability to absorb surplus agricultural production while maintaining productive capacity in the rural sector. In developing countries, biofuels can contribute to rural development in three main areas: employment creation, income generation and by replacing traditional biomass, which is an inefficient and unsustainable energy resource, with modern and sustainable forms of bioenergy.

Economies of scale and the vertical integration required for biofuel production allow little scope for small farmers to benefit. This is particularly true in bioethanol production and will be even more so with second- and third-generation biofuels, unless specific efforts are made to include small farmers in biofuel production schemes. There is more potential for biodiesel to be produced on a smaller scale, although maintaining consistent quality standards will be a problem. Small-scale production of straight vegetable oil requires the least economies of scale and has the greatest potential to benefit small farmers and rural development.

THE IMPORTANCE OF THE TRANSPORT SECTOR

Transportation is responsible for some 30 percent of current global energy usage, practically all in the form of diesel or petrol. Using current technology, biofuels offer the most convenient renewable alternative to fossil transport fuels since they require the fewest changes to the distribution infrastructure. Biofuels produced in sufficient volume could make a significant impact on global warming since it is estimated that transport accounts for 21 percent of total greenhouse gas emissions (Watson *et al*., 1996). Consumption of total liquid fuels will grow by more than a third during the period 2005 to 2030 and, as Figure 2 illustrates, nearly three quarters of this increased demand is expected to come from the transport sector.

PRODUCTION AND CONSUMPTION

Bioethanol is the biofuel most widely used for transportation worldwide. The global annual production of fuel ethanol is around 40 billion litres, of which 90 percent is produced by the USA from maize and by Brazil from

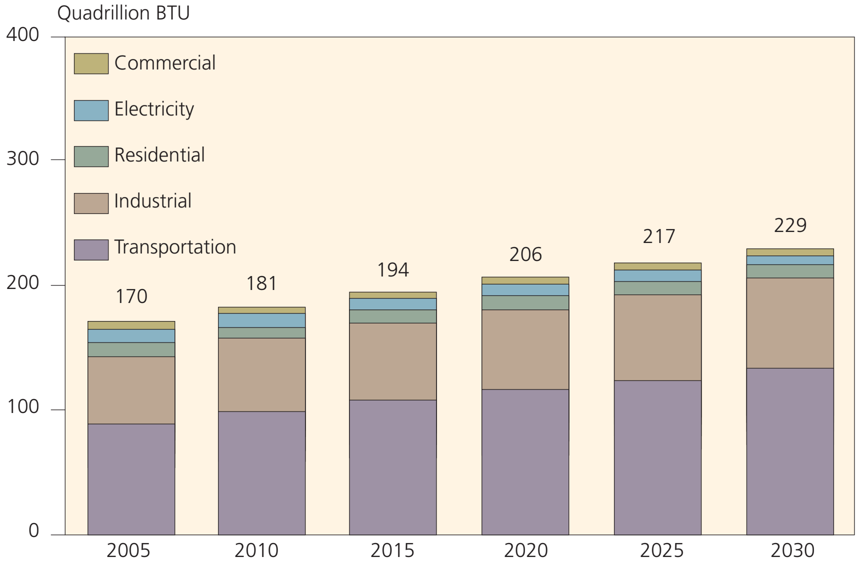


FIGURE 2: **World liquid fuels consumption by sector 2005-2030**

Source: Energy Information Administration (2008).

sugarcane (World Bank, 2008). Global ethanol production has seen steady growth since the search for alternatives to petroleum was prompted by the oil crisis of 1973/4. The USA is now the largest consumer of bioethanol, followed by Brazil. Together they consume 30 billion litres, or three quarters of global production (Licht, 2005).

Global annual production of biodiesel – around 6.5 billion litres – is small compared to bioethanol. The main biodiesel feedstocks are soybean and rapeseed, with the main producers in the Americas and the EU respectively. The EU is by far the largest producer of biodiesel, responsible for 95 percent of world output.

In humid tropics, oil palm is the most important biodiesel feedstock, with Indonesia leading in production followed by Malaysia. Indonesia is projected to increase biodiesel production from 600 million litres in 2007 to 3 billion litres by 2017, which will make it the world's largest producer of palm oil and the second largest producer of biodiesel.

A 2008 analysis by the Energy Information Administration found that nearly half of the increase in world biofuel production between now and 2030 will come from the USA.

THE IMPACTS OF BIOFUELS AND THEIR SUSTAINABILITY

Quantifying how biofuels reduce GHG emissions and how energy efficient they are requires life-cycle analyses (LCAs). LCAs call for a great deal of data and, ideally, take full account of all stages of the production and use of a biofuel, including the GHG emissions and energy efficiencies associated with the resources required for its production. While a fully comprehensive LCA is not yet available, Figure 3 presents a limited LCA of jatropha.

Work in this area shows that the life-cycle energy balance improves and global warming potential decreases when cultivation is less intensive, particularly with less fertilizer and less irrigation, and if the end product is straight vegetable oil rather than biodiesel. The energy-efficient use of the by-products also significantly improves the sustainability and environmental impact of biofuels. However, without plant nutrient management, vegetable oil yields and production will decline – indicating a trade-off between low cultivation intensity and productivity.

Figure 3 shows the energy input required to produce jatropha biodiesel (JME) and offers a comparison with the production of rapeseed biodiesel (RME – rapedseed methyl ester) and mineral diesel. The top horizontal

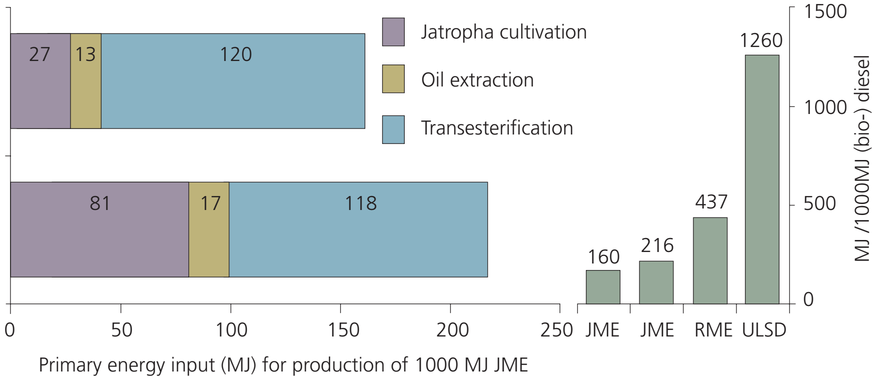


FIGURE 3: **Energy input for the production of jatropha biodiesel at two cultivation intensities, left, and compared to rapeseed methyl ester and mineral diesel, right.**

Source: Tobin and Fulford, cited in Achten *et al.* (2008).

bar, which shows the energy required to produce JME at low cultivation intensity, illustrates that the energy used in cultivation is 17 percent of the total energy input. The lower bar illustrates a higher cultivation intensity, in which cultivation requires 38 percent of the total energy input. The vertical bars to the right show these energy efficiencies for jatropha against the poorer efficiencies of producing biodiesel from rapeseed and for producing mineral ultra low sulphur diesel (ULSD).

However, these analyses do not account for nitrous oxide (N_2O) emissions that result from nitrogen (N) fertilization. N_2O is a gas with a very high global warming potential. Furthermore, it should be noted that clearing natural vegetation to plant jatropha has a negative effect on the GHG balance. Fargione *et al*. (2008) found that converting rainforest, peatlands, savannahs or grasslands to the growing of biofuel crops releases 17 to 420 times more CO_2 than the reductions that occur when these biofuels replace fossil fuels. This underscores the fact that growing jatropha on degraded wastelands with minimal fertilizers and irrigation will have the most positive environmental impact.

Biofuel production also impacts the environment through its effect on water resources and biodiversity. Declining availability of water for irrigation, most notably in India and China, necessitates using the most water-efficient biofuel crops and cropping systems for long-term sustainability. The use of degraded land, conservation agriculture techniques with minimal soil disturbance and permanent soil cover, intercropping and agroforestry systems will lessen negative environmental impact. Biodiversity will be threatened by large-scale monocropping of exotic species.

The main social impacts of biofuels are in the areas of food security, poverty, employment and access to land. Large-scale biofuel schemes – those that require employed labour – have the potential to reduce access to land where land tenure systems are weak, and people may become worse off if there are few checks and controls on employment conditions.

Using food crops for biofuels drives up prices. This means that biofuels are likely to increase the incidence and depth of poverty by making food more costly for net food buyers who account for more than half of the rural poor in developing countries (World Bank, 2008). Certainly in the short term, the majority of poor people will be made poorer by higher food prices.

However, biofuels may also present a significant economic opportunity for the rural poor who mostly rely on agriculture for their livelihoods. Biofuel demand can reverse the long-term decline in real agricultural prices. It is an opportunity for greater investment in agriculture that can lead to higher productivity in industrial crops and food crops, and increased rural employment.

ENERGY POVERTY AND BIOENERGY IN POOR SOCIETIES

The link between poverty alleviation and energy provision makes it critical to consider both when looking toward rural development. Availability of local energy and farm power is fundamental to intensifying agriculture, and agricultural development is essential to poverty alleviation. There is a growing consensus among policy-makers that energy is central to reducing poverty and hunger, improving health, increasing literacy and education, and improving the lives of women and children. Energy pervades all aspects of development – it creates healthier cooking environments, extends work and study hours through the provision of electric light, provides power in remote regions to drive cellular communication equipment, and increases labour productivity and agricultural output by making mechanization possible.

Energy poverty is widespread in the developing world but, as shown in Figure 4, large differences exist among countries. More emphasis could be put on bioenergy as a solution to the needs of the 1.6 billion people who lack access to electricity and on its potential to improve the lives of the 2.4 billion who use traditional biomass (wood fuels, agricultural by-products and dung) for their energy needs. Traditional biomass accounts for 90 percent of energy consumption in poor countries but is often unhealthy, inefficient and environmentally unsustainable.

Two-thirds of the low-income food-deficit countries (LIFDCs) for which data exist are also energy deficient, with 25 of the 47 poorest countries totally dependent on imported fuels. These countries use much of their available funds to import oil with little left to support economic growth.

Oil-importing poor countries have been hit hardest by higher oil prices that have worsened their balance of payments. Biofuels development could improve their foreign exchange reserves, either by substituting for oil imports or by generating revenues through biofuel exports.

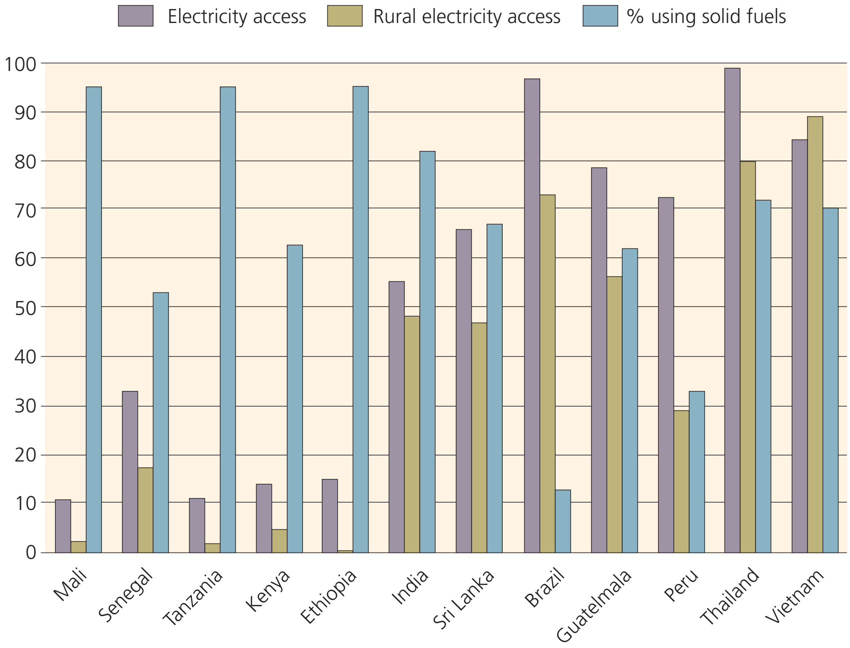


FIGURE 4: **Energy access characteristics for selected countries.**

Source: Practical Action Consulting (2009).

Brazil substitutes sugar for oil

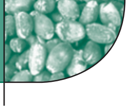
Brazil's use of home-grown biofuels is often held up as an example of oil import substitution. The oil crisis of the 1970s kick-started Brazil's ethanol-from-sugarcane industry, which initially required considerable state subsidies. Now, the industry is not only self sustaining, it has been responsible for savings of more than USD 100 billion, with Brazil using locally produced bioethanol instead of importing oil. At the same time, it has made Brazil the world's largest exporter of sugarcane-derived bioethanol (Moreira, 2006). Land availability and suitable agroclimatic conditions of Brazil played important parts in the success of this initiative. Brazil is now promoting the production of sugarcane on degraded pasture lands, thus providing environmental services as well as economic growth.

However, addressing energy poverty in remote rural areas requires more than relying on biofuel crop production to raise incomes. There is a need to have sustainable systems of biofuel production, processing and simple utilization technology in place.

JATROPHA – GLOBAL AND REGIONAL PRODUCTION AND TRENDS

The jatropha industry is in its very early stages, covering a global area estimated at some 900 000 ha. More than 85 percent of jatropha plantings are in Asia, chiefly Myanmar, India, China and Indonesia. Africa accounts for around 12 percent or approximately 120 000 ha, mostly in Madagascar and Zambia, but also in Tanzania and Mozambique. Latin America has approximately 20 000 ha of jatropha, mostly in Brazil.

The area planted to jatropha is projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2015. By then, Indonesia is expected to be the largest producer in Asia with 5.2 million ha, Ghana and Madagascar together will have the largest area in Africa with 1.1 million ha, and Brazil is projected to be the largest producer in Latin America with 1.3 million ha (Gexsi, 2008).



CHAPTER 2

Jatropha curcas L.

ORIGIN AND SPREAD

Jatropha is believed to have been spread by Portuguese seafarers from its centre of origin in Central America and Mexico via Cape Verde and Guinea Bissau to other countries in Africa and Asia. It is now widespread throughout the tropics and sub-tropics.

Until recently, jatropha had economic importance in Cape Verde. Since the first half of the nineteenth century, with its ability to grow on poor soils with low rainfall, it could be exploited for oilseed production. Cape Verde exported about 35 000 tonnes of jatropha seeds per year to Lisbon. Along with Madagascar, Benin and Guinea, it also exported jatropha seeds to Marseille where oil was extracted for soap production. However, this trade declined in the 1950s with the development of cheaper synthetic detergents and, by the 1970s, the trade in jatropha oil had disappeared (Wiesenhütter, 2003; Henning, 2004a).

In the past, jatropha oil was used for lighting lamps (Gübitz *et al*., 1998). Today, rural communities continue to use it for its medicinal value and for local soap production. India and many countries in Africa use the jatropha plant as a living hedge to keep out grazing livestock. Jatropha is planted in Madagascar and Uganda to provide physical support for vanilla plants.

Jatropha's potential as a petroleum fuel substitute has long been recognized. It was used during the Second World War as a diesel substitute in Madagascar, Benin and Cape Verde, while its glycerine by-product was valuable for the manufacture of nitro-glycerine.

Photo: BRITTAINE

PLATE 1: *Jatropha curcas* L., Andhra Pradesh, India.

NOMENCLATURE AND TAXONOMY

Jatropha curcas L. (see Plate 1) was first described by Swedish botanist Carl Linnaeus in 1753. It is one of many species of the genus *Jatropha*, a member of the large and diverse *Euphorbiaceae* family. Many of the *Euphorbias* are known for their production of phytotoxins and milky white sap. The common name "spurge" refers to the purgative properties of many of these *Euphorbias*.

There are some 170 known species of jatropha, mostly native to the New World, although 66 species have been identified as originating in the Old World (Heller, 1996). A number of jatropha species are well known and widely cultivated throughout the tropics as ornamental plants. The literature identifies three varieties: Nicaraguan (with larger but fewer fruits), Mexican (distinguished by its less-toxic or non-toxic seed) and Cape Verde. The Cape Verde variety is the one commonly found throughout Africa and Asia. *Jatropha curcas* L. has many vernacular names including: physic nut or purging nut (English), *pinhão manso* or *mundubi-assu* (Brazil), *pourghère* (French), *purgeernoot* (Dutch), *Purgiernuss* (German), *purgeira* (Portuguese), *fagiola d'India* (Italian), *galamaluca* (Mozambique), *habel meluk* (Arab), *safed arand* (Hindi), *sabudam* (Thai), *bagani* (Ivory Coast), *butuje* (Nigeria), *makaen* (Tanzania), *piñoncillo* (Mexico), *tempate* (Costa Rica) and *piñon* (Guatemala).

DESCRIPTION

Jatropha, a succulent perennial shrub or small tree, can attain heights of more than 5 metres, depending on the growing conditions. The photos in Plates 2 and 3, taken in Andhra Pradesh, India, clearly show the effect of water and nutrient stress on plant size. In each case, the trees are slightly more than two years old.

Seedlings generally form a central taproot, four lateral roots and many secondary roots. The leaves, arranged alternately on the stem, are shallowly lobed and vary from 6 to 15 cm in length and width (see Plate 4). The leaf size and shape can differ from one variety to another. As with other members of this family, the vascular tissues of the stems and branches contain white latex. The branches and stems are hollow and the soft wood is of little value.

Jatropha is monoecious, meaning it carries separate male and female flowers on the same plant. There are fewer female than male flowers and these are carried on the apex of the inflorescence, with the more numerous males borne lower down. The ratio of male to female flowers averages 29:1 but this is highly variable and may range from 25-93 male flowers to 1-5 female flowers produced on each inflorescence (Raju and Ezradanum,


Photo: BRITTAINE

PLATE 2: Jatropha with adequate water and nutrients.


Photo: BRITTAINE

PLATE 3: Jatropha growing in dry marginal soils.

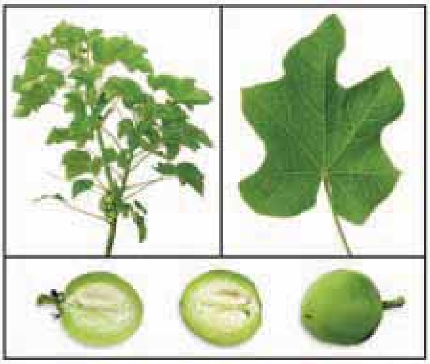


Photo: GODOFREDO STUART

PLATE 4: **Jatropha leaf and fruit.**

Photo: HENNING

PLATE 5: **Jatropha flowers.**

2002). It also has been reported that the male-to-female flower ratio declines as the plant ages (Achten *et al.*, 2008), suggesting that fruiting capacity may increase with age.

The unisexual flowers of jatropha (see Plate 5) depend on pollination by insects, including bees, flies, ants and thrips. One inflorescence will normally produce 10 or more fruits. Fruit set generally results from cross pollination with other individual plants, because the male flowers shed pollen before the female flowers on the same plant are receptive. In the absence of pollen arriving from other trees, jatropha has the ability to self pollinate, a mechanism that facilitates colonization of new habitats (Raju and Ezradanum, 2002).

The fruits are ellipsoidal, green and fleshy, turning yellow and then brown as they age. Fruits are mature and ready to harvest around 90 days after flowering. Flowering and, therefore, fruiting are continuous, meaning that mature and immature fruits are borne together. Each fruit contains two or three black seeds, around 2 cm x 1 cm in size. On average, the seeds contain 35 percent of non-edible oil. The immature and mature fruits are shown together with the seed in Plate 6.

Jatropha grows readily from seed which germinate in around 10 days, or from stem cuttings. Growth is rapid. The plant may reach one metre and flower within five months under good conditions (Heller, 1996). The growth is sympodial, with terminal flower inflorescences and lateral branching, eventually reaching a height of 3 to 5 metres

Photo: BRITTAINE

PLATE 6: **Jatropha fruit and seeds.**

under good conditions. It generally takes four to five years to reach maturity (Henning, 2008a).

Vegetative growth occurs during the rainy season. During the dry season, there is little growth and the plant will drop its leaves. Flowering is triggered by rainfall and seed will be produced following the end of the rainy season. Seeds are produced in the first or second year of growth. Jatropha trees are believed to have a lifespan of 30 to 50 years or more.

USES OF JATROPHA

With the present interest in the energy-producing potential of jatropha, it is useful to look at the attributes, both positive and negative of the plant, and to compare the relative energy values of its different parts. Figure 5 (see page 21) presents a summary of the various uses of jatropha that have been reported in relation to their energy values. It is interesting to note that the energy content of the remaining parts of the fruit after oil extraction exceeds the energy content of the oil.

The jatropha tree

Erosion control and improved water infiltration

Jatropha has proven effective in reducing the erosion of soil by rainwater. The taproot anchors the plant in the ground while the profusion of lateral and adventitious roots near the surface binds the soil and keeps it from being washed out by heavy rains. Jatropha also improves rainwater infiltration when planted in lines to form contour bunds. Furthermore, jatropha hedges reduce wind erosion by lessening wind velocity and binding the soil with their surface roots (Henning, 2004a).


Photo: MALI-FOLKECENTRE

PLATE 7: **Jatropha hedge in Mali, West Africa.**


Photo: GOERGEN

PLATE 8: **Jatropha hedge planted with agave, Madagascar.**

However, these anti-erosion effects are limited by dry season leaf drop. This means there is less protection at a time when wind erosion is highest and there is no leaf canopy to protect the soil when the first heavy rains fall. This can be ameliorated by growing drought-resistant ground cover plants such as agave, as shown in Plate 8. It appears that jatropha has little negative allelopathic effect on other plants (Weisenhutter, 2003).

Livestock barrier and land demarcation

In many tropical and subtropical countries, jatropha cuttings are planted as a hedge to protect gardens and fields from wandering animals (see Plates 7 and 8). Livestock will not eat the mature leaves and even goats will die of starvation if there is only jatropha to browse (Henning, 2004a). For the same reason, jatropha is often planted to mark homestead boundaries. Hedges planted very close together (5 cm) form a barrier that is impenetrable even by chickens.

Fuelwood

The wood of jatropha is soft and hollow and, contrary to some reports in the literature, is not good fuelwood. Jatropha groves on the islands of

Cape Verde have been used as a fuelwood source, mainly due to the lack of other suitable species.

Support for vanilla

Jatropha is grown as a support and shade tree in smallholder vanilla farms in Madagascar and Uganda. The tree stems are pruned while the canopy is left to provide shade. As a result, vanilla plantations report low jatropha seed yields of around 200 kg per ha (Henning, 2004a).

Green manure

Jatropha trees grown from seed develop taproots. Thus, they are able to extract minerals that have leached down through the soil profile and return them to the surface through leaf fall, fruit debris and other organic remains. In this way, jatropha acts as a nutrient pump which helps rehabilitate degraded land.

Plant extracts

Jatropha plant extracts have many uses in traditional societies (Heller, 1996). The dried latex resembles shellac and is used as a marking ink. The leaves and bark are used for dyeing cloth.

Jatropha has medicinal qualities, including a blood coagulating agent and antimicrobial properties that are widely used in traditional medicine and for veterinary use. All parts of the plant are used. Some of these uses that are briefly described below are to some extent anecdotal.

Stem

The latex has a widespread reputation for healing wounds and stopping bleeding, and for curing various skin problems. It is used against pain and the stings of bees and wasps. The fresh stems are used as chewing sticks to strengthen gums and treat gum disease.

Bark and roots

The bark has a purgative effect similar to that of the seeds. In the Philippines, fishermen use the bark to prepare a fish poison. The dried and pulverized root bark is made into poultices and taken internally to expel worms and to treat jaundice. A decoction of the roots is used to treat diarrhoea and gonorrhoea.

Leaves

The leaves also have a purgative effect. Applied to wounds and in decoction, they are used against malaria and to treat hypertension. The leaf sap is used externally to treat haemorrhoids. A hot water extract of the leaves is taken orally to accelerate secretion of milk in women after childbirth. A decoction is used against cough and as an antiseptic following childbirth.

Seeds

The oil-rich seeds and seed oil are used as a purgative and to expel internal parasites. The oil is applied internally and externally to induce abortion, and externally to treat rheumatic conditions and a variety of skin infections. The oil is also an ingredient in hair conditioners.

Fruits and seeds

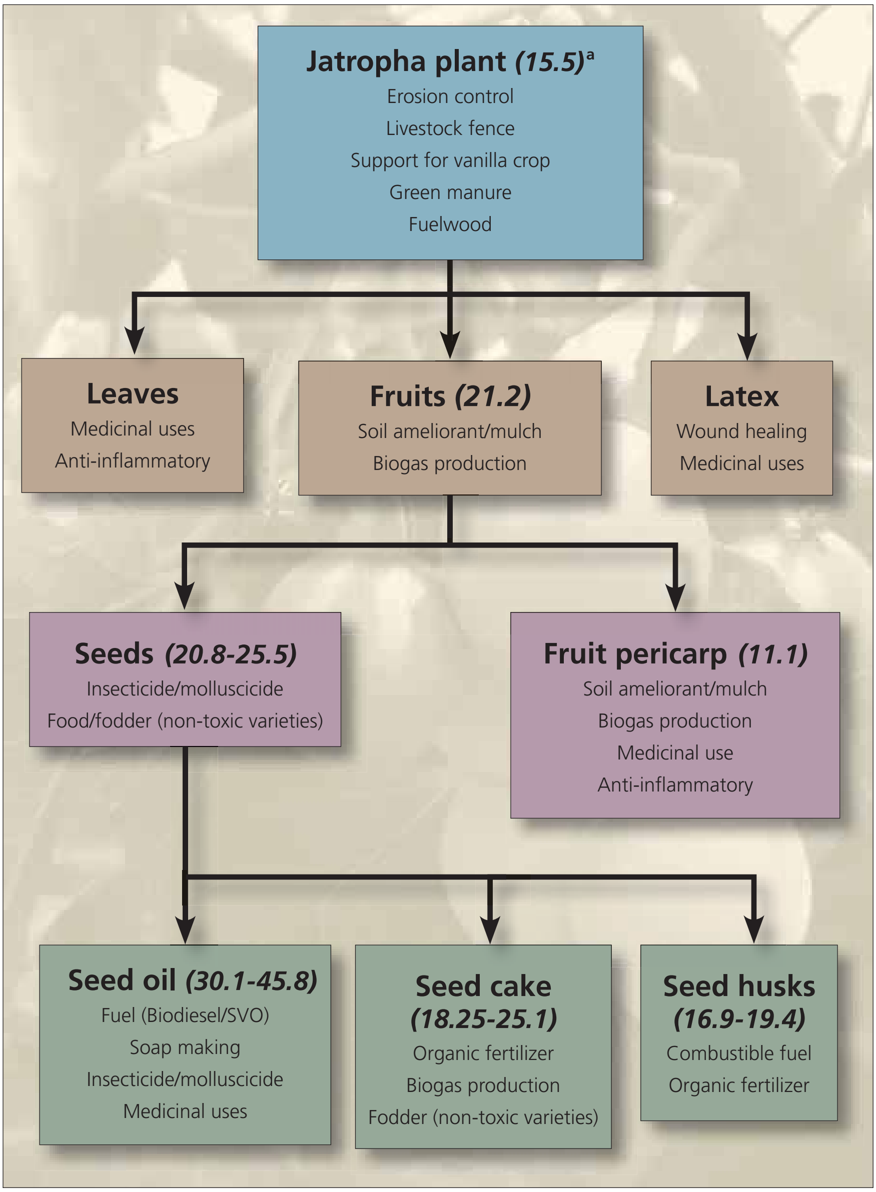
A full account of the uses of the harvested fruit is given in Chapter 4. Besides the current interest in the use of the seed oil for biofuel, it is also used for making soap on a small scale and for illumination. In China, the oil is boiled with iron oxide and used to produce furniture varnish. Extracts of the seed oil have been found effective against a number of crop pests and snail vectors of schistosomiasis.

TOXICITY AND INVASIVENESS

Toxicity

Although the seeds are considered the most toxic part of the plant, all parts of the jatropha plant contain toxins such as phorbol esters, curcins and trypsin inhibitors (Jongschaap, 2007). Varieties commonly found growing in Africa and Asia have seeds that are toxic to humans and animals, whereas some varieties found in Mexico and Central America are known to be non-toxic.

The poisonous and anti-nutrient properties of the seeds are exploited in traditional medicine for de-worming and as a purgative. Just one to three seeds can produce toxic symptoms in humans, mainly those associated with gastro-intestinal irritation. There is acute abdominal pain and a burning sensation in the throat shortly after ingestion of the seeds, followed by nausea, vomiting and diarrhoea. Children are more susceptible. There is



[a] Energy values of the components are given in MJ kg^{-1}.

FIGURE 5: The uses of *Jatropha curcas* and the energy values of its components.

Source: Adapted from Gubitz *et al.* (1999).
Energy values are ranges taken from various sources cited in Jongschaap (2007) and Achten (2008).

no known antidote, but case studies indicate that following accidental ingestion, often by children, full recovery is usual (IPCS, n.d.).

Toxicity is chiefly due to the presence of phorbol esters, as inferred from the fact that non-toxic Mexican jatropha varieties are deficient in these compounds. Phorbol esters are known to be co-carcinogenic, meaning that they are tumour promoting in the presence of other carcinogenic substances. It has been reported that phorbol esters decompose rapidly – within six days – as they are sensitive to light, elevated temperatures and atmospheric oxygen (Rug and Ruppel, 2000, cited Jongschaap, 2007), but there is no supporting data for this. The decomposition of these and other toxic compounds in the field needs further evaluation before insecticide or molluscicide oil extracts can be widely used, or before the widespread application of seed cake as fertilizer, particularly on edible crops, given that there is no information as to whether such compounds are taken up by plants.

Curcin has been described as a major toxic component of jatropha, similar to ricin which is a well known poison. Yet, experiments on mice suggest that curcin is, in fact, innocuous and has a median lethal dose (LD_{50}) some 1000 times that of ricin. Curcin is commonly found in edible plants (King *et al.*, 2009).

For toxic varieties of jatropha, all the products, including the oil, biodiesel and the seed cake, are toxic. Laboratory-scale detoxification of the seed cake to render it usable as a livestock feed is possible, but it is not straightforward and is unlikely to be economically feasible on a small scale.

Mexico has varieties of *Jatropha curcas* that are not poisonous and, in fact, Gubitz (1999) reported that wildlife and livestock feed on the seeds, and that traditional Mexican dishes use the boiled and roasted seeds. Using these varieties in future breeding programmes is the most likely route to non-toxic jatropha products.

Invasiveness

The fact that jatropha can grow and colonize areas that are inhospitable to other plants makes it a potentially invasive species. While some field observers have stated that the plant is not invasive (Henning, 2004a), Australia's Northern Territory and Western Australia have declared it a noxious weed and have biological control programmes in place for its close relative *Jatropha gossypiifolia*. South Africa bans commercial production of *Jatropha curcas* due to these environmental concerns. Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto Rico and El Salvador classify it as a weed.

The Global Invasive Species Programme (GISP) has developed a list of species being considered as biofuel feedstocks that are potentially invasive. It also has compiled the following recommendations for governments considering development of biofuels (GISP, 2008).

- **Information gathering:** check national noxious weed lists, databases and Web sites for references relevant to the countries where biofuel developments are proposed.
- **Risk assessment:** use formal risk assessment protocols to evaluate the risk of invasion by species in biofuel proposals, with particular attention and support to countries with less experience in addressing biological invasions or screening for impacts on biodiversity.
- **Benefit/cost analysis:** conduct market studies and present business plans that show real benefits for the proposed activities before funds are made available, as there are many known cases of introduced species that have never achieved commercial value and, instead, have become actual or potential problems.
- **Selection of native or low-risk species:** create incentives for the development and use of native and/or non-native species that pose the lowest risks to biodiversity.
- **Risk management:** develop monitoring and contingency plans, such as control in case of escape, in proposals for biofuels, particularly biodiesel. Invasive species that are normally dispersed by animals and other active means must not be used without viable and well-tested control procedures and contingency plan for escapes.
- **Certification/accreditation processes:** evaluate project proposals according to criteria and/or certification schemes for sustainable biofuels development. A number of such processes are underway at the national and international levels.

Pest Risk Analysis (PRA) and Pest Risk Management (PRM) are tools developed by the European and Mediterranean Plant Protection Organization (EMPPO) to “evaluate biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it."[2] The EMPPO's PRA is part of the International Standard for Phytosanitary Measures (ISPM) on PRA that has been developed in the International Plant Protection Convention (IPPC) framework.

The strengths and weaknesses of jatropha are summarized in Boxes 1 and 2 respectively.

BOX 1. **Jatropha – Strengths**

- Jatropha has the potential, through varietal improvement and good farming practices, for a high level of oil production per unit area in the subhumid tropical and subtropical environments.
- Jatropha grows and is potentially productive in semi-arid areas on degraded and saline soils.
- Jatropha can be used for halting and reversing land degradation.
- Jatropha grows fast, as compared to many other tree-borne oilseeds.
- Jatropha trees remain small, enabling ease of management.
- Jatropha has periodic leaf shedding which facilitates nutrient recycling and dry season irrigated intercropping with short-term crops.
- Jatropha leaves are unpalatable to grazing livestock, making it a good barrier hedge to protect crops.
- Jatropha oil has physical and chemical properties that make it highly suitable for processing into biodiesel.
- Jatropha oil can be used directly in suitable diesel engines, lamps and cooking stoves.
- Jatropha by-products have potential value, such as using seed cake as fertilizer, animal feed (non-toxic varieties) or biogas, and using fruit shells and seed husks for biogas and combustion.
- Jatropha oil has markets other than for fuel, such as the production of soap, medicines and pesticides.
- Jatropha seeds are storable and processing can be delayed, which makes production suited to remote areas.
- Jatropha has attracted investment, mainly from the private sector, into plant breeding, which increases the likelihood of developing jatropha varieties with improved and stable oil yields.

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[2] See http://www.eppo.org/QUARANTINE/Pest_Risk_Analysis/PRA_intro.htm.

BOX 2. **Jatropha - Weaknesses**

- Jatropha research has not yet identified varieties that are reliably high yielding.
- Jatropha trees vary greatly in yield, oil content and oil quality.
- Jatropha can survive poor growing conditions but, in the absence of sufficient water and nutrients, it has poor yields.
- Jatropha agronomic and production system information is lacking, most importantly for the reliable prediction of yield.
- Jatropha cultivation has potential environmental risks and benefits, which have not been identified sufficiently.
- Jatropha takes 3–5 years to reach economic maturity, which is longer than annual oilseed crops.
- Jatropha yield expectations touted in the popular press are overly optimistic, with high probability that some farmers may well lose interest before improved genotypes and agronomic practices are in place.
- Jatropha toxicity prevents use of the seed cake for livestock feed, which otherwise would add significant value.
- Jatropha toxicity may present a health risk to plantation workers, children and livestock.
- Jatropha harvesting is labour intensive and mechanization is difficult due to the poor synchronicity of fruiting.
- Jatropha is susceptible to pests and diseases when grown as a plantation monocrop, although not more so than other crops.
- Jatropha wood is soft and not good for burning or construction.
- Jatropha is not frost tolerant and cannot tolerate waterlogging.
- Jatropha may act as a host for cassava diseases.
- Jatropha oil is less suited to direct use as a mineral diesel substitute in cool climates due to its viscosity, which is higher than rapeseed oil.
- Jatropha may become a weed problem in certain environments.

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