Jatropha curcas L.: Development of a new oil crop for biofuel (Summary)

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The biofuel development boom has sparked concerns over deforestation and food issues and created a tendency to level criticism on the diversion of edible oil to fuel production. The nonfood oil plant *Jatropha curcas L.* appeared on the scene as the favorite response to this criticism. But, experience cultivating *Jatropha curcas L.* as a crop is still shallow and agricultural techniques have yet to be established. A period of R&D will be needed to establish *Jatropha curcas L.* as a plantation crop that can be cultivated on a commercial basis. Regardless, many countries and companies are going ahead and injecting capital into the development of large-scale plantations, which is an alarming situation. Accordingly, this paper provides as much basic information as possible about *Jatropha curcas L.* as a plant, given that there is a dearth of such information at present. Further, the paper introduces the existence of a number of barriers and challenges that must be overcome to develop *Jatropha curcas L.* as raw material crop, including the establishment of upstream cultivation techniques, improved breeds, farm management know-how, intermediary distribution, processing, and refinement methods, and application technologies in the downstream market. The paper also summarizes the development of *Jatropha curcas L.* in Asia and considers the future potential of this industry.

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Introduction

Soaring crude oil prices, global warming, and other macroeconomic trends in the international energy market have raised the profile of biofuels. Led by the U.S.'s ethanol policy and the EU Biofuel Directive, national governments around the world are adopting biofuel policies one after the other, driving mounting expectations on the biofuel industry. On the other hand, expansion of the biofuel industry has led to concerns about its relation to food, environmental, and political problems. In many debates the biofuel industry's impact on food supplies is the greatest concern. Palm oil, soybean, rapeseed, coconut, and other traditional oil crops are all produced to extract edible oil. But, some are now pointing out that the diversion of these crops to fuel production is difficult to accept, considering the blow delivered, especially to the poor, by the effect on food supplies and prices. Expectations on palm oil, which is especially competitive as a raw material for biofuel, have shot up following the rapid rise in crude oil prices. However, the concentration of demand on palm oil has worsened the effect on food and deforestation and led to increased international criticism of the adoption of palm oil as a raw material for biofuel.

Pushed by this sort of world opinion, national governments and companies have turned their attention to *Jatropha curcas L.*, a poisonous nonfood plant. As a biofuel crop *Jatropha curcas L.* would not compete with food crops since, it is asserted, it can be cultivated in wasteland instead of agricultural land. With conventional oil crops for biodiesel being criticized for their competition with food, *Jatropha curcas L.* came into the spotlight because it does not put pressure on the food supply. However, most of the currently widespread information about *Jatropha curcas L.* is not based on research data supported by sufficient evidence, and much of it contains mistakes. In light of the present dearth of information, this paper presents basic botanical information on *Jatropha curcas L.*, introduces development trends centered in Asia, and considers its future development potential.

1. Basic botanical information on *Jatropha curcas Linn.*

The attention being given to *Jatropha curcas L.* did not start especially recently. The United Nations (UN) has been promoting the cultivation of *Jatropha curcas L.* as a measure to fight poverty in African countries since before crude oil prices started to rise sharply. As a fuel measure in poor rural communities, the UN has been encouraging farmers to use the oil obtained from *Jatropha curcas L.* cultivated on land that is unfit for agriculture as a daily-use fuel. As a result, *Jatropha curcas L.* gained a worldwide reputation as a plant that can be grown in wasteland and infertile land, does not require much water, fertilizer, and management, and has high oil content. However, when development of *Jatropha curcas L.* started later on a commercial basis, these exaggerated characterizations were the cause of numerous misunderstandings. Before going into more detail about this, below is an overview of the features and properties of *Jatropha curcas L.*.

1.1 Features of *Jatropha curcas L.*

(1) Botanical classification and features

Jatropha curcas L. is classified as follows:

Division	: Spermatophyta
Class	: Dicotyledonae
Family	: Euphorbiaceae
Genus	: Jatropha
Botanical name	: *Jatropha curcas L.*

The name jatropha is thought to be derived from "*iatros*", meaning physician in Yunani,[1] and the Greek "*trophe*" (food or nourishment). Jatropha grows all around the world and has been confirmed in a wide range of regions. More than 170 species have been identified in the jatropha genus. Within the jatropha genus, *Jatropha curcas L.* has gained attention as a biodiesel crop. *Jatropha curcas L.* is held to have been classified and named by Carl Linnaeus in 1753.

Said to have originated in the Caribbean, *Jatropha curcas L.* is thought to have become naturalized in Asia after being brought to the region by Europeans during the age of exploration. At the time, the colonial policies implemented by European countries prompted a flood of ships to arrive in Southeast Asia in search of spices. *Jatropha curcas L.* is believed to have been used as a fuel for lighting and cooking onboard these ships. However, no literature clearly indicating these matters has been found. Accordingly, more research is needed regarding the actual route of propagation, since *Jatropha curcas L.* is found widely in areas that were not colonized, including Thailand and Sichuan, Guangxi, Yunnan, and Hainan provinces in southern China.

At present, *Jatropha curcas L.*'s range is very wide. Including its native Caribbean, the plant grows in all climates from tropical to subtropical zones on each continent. This wide range is in part

[1] Yunani is a language spoken in the Mediterranean region. It is an offshoot of Greek rooted in the Indo-European language family. Nowadays, it is used chiefly on the Republic of Cyprus, an island nation in the Mediterranean Sea.

attributable to *Jatropha curcas L.*'s exceptional toughness and its ability to adapt to environmental changes. *Jatropha curcas L.* is known by different common names in each region, some of the better known ones being *physic nut* (English), *purgiemuss* (German), *pignon d'lnde* (French), *bagbherenda* (Hindi), *jarak pagar* (Indonesian/Malaysian), *sabuu dam* (Thai), *xiao tong zi* (Chinese), and *nanyo aburagiri* (Japanese).

(2) Propagation

Jatropha curcas L. is regarded as a relatively undemanding plant to cultivate, since it can be propagated easily by seed and layering. Moreover, being a succulent plant it can be widely cultivated in arid regions, since its leaves and roots store large amounts of water during dry periods. It is well suited to regions with annual rainfall averaging between 480-2,380 mm, but it can also grow in regions with as little as 200-1,500 mm of rainfall per year. Besides water, *Jatropha curcas L.* does not require much fertilizer and can inhabit denuded, marginal, and other poor land as well as land as elevations between 500-1,000 meters. Although it is highly adaptable to temperature, it needs temperatures of at least 20 degrees Celsius to grow well.

Figure 1 *Jatropha curcas L.* flowers, fruit, and seeds


Flower


Fruit


Cut fruit


Seeds

Source: BDF Malaysia Sdn. Bhd.

(3) Cultivation

Generally, *Jatropha curcas L.* starts producing fruit in about one year[2] and reaches a stable harvesting stage after five years. It has a lifespan of about 50 years and an estimated economically productive period of about 25-30 years. But, the production curve is practically unknown, since there are no actual production results on a commercial basis. After five years, the plant is said to produce 3-12 tons of seeds per hectare per year depending on weather and management conditions.[3]

The oil content of seeds varies by variety, weather conditions, and region. India's Energy and Resource Institute (TERI) has reported an oil content of 25-38%. Generally, however, it has been reported that pressing oil directly from the entire seed typically results in an oil extraction rate of about 25-30% and produces about 1.5 tons of oil per hectare. Thus, the average yield of *Jatropha curcas L.* oil per unit area is low compared to the approximately 4 tons for palm oil. However, no commercial plantations have been formed, and thus far the plant's uses have been limited to cultivation mainly as a hedge by farmers or for traditional medicinal preparations. Consequently, it has not been selectively bred for the purpose of increasing seed yields per unit area.

1.2 Conversion of *Jatropha curcas L.* to biofuel

Jatropha curcas L. oil (crude jatropha oil; "CJO" below) is obtained only after going through the following steps: collection of fruit from the trees, separation of seeds from the peel and flesh (pericarp), seed drying,[4] oil pressing, and filtration. Advanced management know-how from cultivation through harvesting would be necessary to develop a commercial plantation.

One fruit contains three seeds, and one seed averages 0.7 grams.[5] Each seed is composed of a shell (± 35%) and a kernel (± 65%).[6] Pressing oil from the kernel yields kernel cake (40-50%) and crude oil (50-60%). At present, in the majority of cases oil is generally pressed directly from the seed without separating the kernel and shell. This method produces seed cake (70-75%) and crude oil (25-30%). Kernel cake and seed cake are protein rich and can be processed in to fertilizer or feed. However, since these cakes contain curcin, a toxic protein, in most cases it is presumed that they will be converted to organic fertilizer or a solid biomass fuel in the form of pellets or briquettes. Figure 2 shows the component ratios obtained when pressing oil from the kernel and when pressing oil directly from the seed.

If the process from the collection of *Jatropha curcas L.* fruit to the extraction of CJO is not managed appropriately, the content rate of free fatty acids (FFA) in the produced CJO increases,

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[2] It flowers in six months in tropical humid climates such as in Malaysia, Indonesia, and Brazil, but generally flowers after about one year in places by India, China, and Vietnam.

[3] Seed yields differ greatly depending on the cultivation conditions. Weather, soil, cultivation techniques, management know-how, and other conditions would have to come together to undertake commercial production.

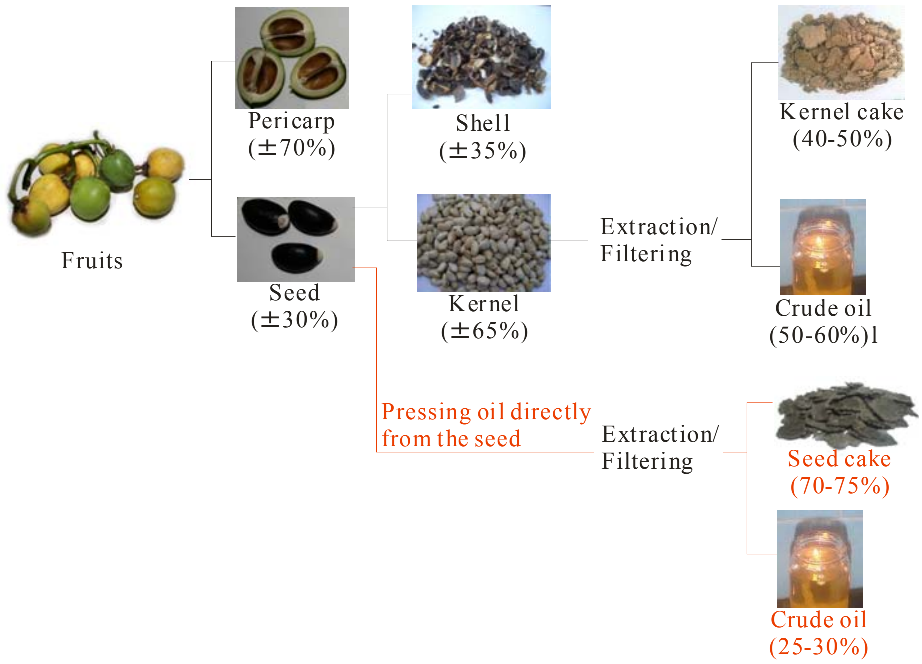
[4] Seeds dry naturally in about three days depending on the shade conditions.

[5] Seed weight varies according to the variety and regional climate. Generally, 0.5-0.8 grams is common.

[6] Generally, the moisture content of a dried seed is about 5%.

affecting the biodiesel refinement process. Accordingly, measures must be taken to prevent this by treating the fruit soon as harvesting. When used as biodiesel, CJO is maintained to have advantages such as a high saturated fatty acids content, high oxidation stability, and good low temperature fluidity.[7]

Figure 2 Weight of products and byproducts from *Jatropha curcas L.*



Source: BDF Malaysia Sdn. Bhd.

Table 1 Chemical properties of jatropha oil

Parameter	Unit	Value
Acid Value	mg KOH/g oil	38.2
Saphonification value	mg KOH/g oil	195.0
Lodin value	mg iod/g oil	101.7
Fatty acid composition	%	
Palmitic		14.2
Stearic		6.9
Oleic		43.1
Linoleic		34.3
Others		1.4

Source: Surfactant and Bioenergy Research Center (SBRC), Bogor Agricultural University

7 BP interview (February 2008).

Table 2 Physical properties of jatropha oil

Property	Unit	Value
Flashpoint	°C	236
Density (15°C)	g/cm3	0.9177
Viscosity (30°C)	nm2/s	49.15
Carbon residue	%(m/m)	0.34
Ash / sulfuric acid	%(m/m)	0.007
Pour point	°C	-2.5
Water content	ppm	935
Sulfur content	ppm	<1
Cetane number*		39
Calorific value*	MJ/kg	39.35

Source: Hamball et al (2006), * Valtllngom and Liennard (1997) in Gubitz et al (1997)

The table below shows the properties of a blend of 20% biodiesel made from Indian *Jatropha curcas L.* and Indian light oil. Blends with biodiesel derived from palm oil are shown as a contrast. FAEE (fatty acid ethyl ester) refers to biodiesel that uses ethanol in contrast to FAME (fatty acid methyl ester), which is biodiesel that uses methanol. These are the properties after mixing with light oil, but it can still be seen that the cold filter plug point (CFPP) is lower than that for palm oil. The CFPP and sulfur content are insufficient compared to Japan's light oil standards, but a simple comparison cannot be made, since the properties of a blend of 80% light oil are different.[8]

Table 3 Properties of light oil-biodiesel blends made using jatropha

Property	Unit	Indian light oil standard	Jatropha oil B20 (FAME)	Palm oil B20 (FAME)	Japanese light oil standard
Cetane number (min.)	―	46 or more	50	50.3	45
Lubricity (60° C, max.)	μm	460	260	260	-
Flashpoint (min.)	°C	35	70	70	(45)
Viscosity (37.8)	mm^2/s	2.0-5.0	3.284	3.534	(1.7-2.7) @ 30°C
Sulfur content (max.)	ppm	500	235	270	10
CFPP (max.)	°C	18 (summer), 6 (winter)	-2	0	(-1 to -19)

Source: Society of Indian Automobile Manufacturers (SIAM). Values in parentheses in the Japanese standards column are those of the Japanese Industrial Standards (JIS), since there are no equivalent items in the Japanese standards law.

2. *Jatropha curcas L.* development by different companies and countries

2.1 Initiatives of major companies

(1) DaimlerChrysler AG

8 Table 3 and its explanation were written by Takao Ikeda of the New and Renewable Energy Group of the Institute of Energy Economics, Japan.

Daimler spent five years, beginning in November 2003, conducting development research with a local Indian research institution, working on a range of matters from the development of *Jatropha curcas L.* plantations to fuel commercialization. During the five-year research period, the company developed two pilot *Jatropha curcas L.* plantations and obtained approximately 1 ton of jatropha oil per hectare as an initial result.[9] This result was rated highly, since the project was conducted on land with relatively poor conditions.

In April 2004, the company conducted a combustion experiment on *Jatropha curcas L.*-derived biodiesel fuel in cooperation with the Central Salt & Marine Chemicals Research Institute (CSMCRI) located in the state of Gujarat in India and Germany's University of Hohenheim. The experiment was run in a Mercedes-Benz C 220 CD model over a total distance of 5,900 km during five months of validation test driving.[10] The announced result was that jatropha oil as a biodiesel fuel has a quality comparable to that of rapeseed oil.

On January 9, 2008, Daimler announced that it would team up with U.S.-based Archer Daniels Midland (ADM), a major food processor, and German-based Bayer CropScience, the world's largest chemical pesticide maker, and jointly develop *Jatropha curcas L.* biodiesel fuel.[11]

(2) BP

Unlike the independent initiatives undertaken by Daimler, oil major BP established a 50/50 joint venture called D1-BP Fuel Crops Limited with D1 Oils, a company that originally worked on soybean-derived biodiesel. According to an announcement by BP made on June 29, 2007, the two companies will invest about $160 million in the project over the next five years. Although the form of the investment plan has not been disclosed, the companies apparently intend to develop a total of one million ha of new *Jatropha curcas L.* plantations by 2011 and produce about two million tons of biodiesel per year.[12]

D1 Oils was the first company in the world to develop *Jatropha curcas L.* plantations. The scope of this activity spans tropical and subtropical regions in Africa, South America, Southeast Asia, India, and China. These endeavors have not necessarily gone smoothly, however, since there are many uncertainties, including productivity and plantation management techniques for *Jatropha curcas L.*. According to the information for each country in Southeast Asia, almost all the developed land area announced by D1 Oils is in the form of contract farming while the area of plantations directly managed by the company is extremely small. The company has developed a plantation in southern Sumatra in Indonesia that uses agricultural land and is in fact affecting the planting of existing crops.

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9 DaimlerChrysler AG "360 Degrees – Magazine on Sustainability 2007," Page 31.

10 Daimler Chrysler "Innovations for our Customers, Annual Report 2004," page 76-77.

11 Thomson Reuters 2008, http://www.reuters.com/article/rbssConsumerGoodsAndRetailNews/idUSL0932139720080109

12 According to a press release on BP's website, http://www.bp.com/genericarticle.do?categoryId=1015&contentId=7034664

(3) Major Chinese oil companies

The Chinese government had an active stance on the development of biofuel, and had been working on the production of ethanol from old stocks of corn since 2003. However, with the escalation of food security problems in the country, the central government severely restricted the use of new biofuels made from principal grain foods. Consequentially, China started large-scale development of *Jatropha curcas L.*, which is a non-food, in the southern part of the country. The leaders of this development are the major state-run oil companies.

In cooperation with the State Forestry Administration, China National Petroleum Corporation (CNPC) is developing *Jatropha curcas L.* plantations mainly in Yunnan and Sichuan provinces. The current plan is to plant an area of approximately 40,000 ha and to set up biodiesel refining equipment in the two provinces, giving each an output capacity of 10,000 tons per year.

China Petroleum & Chemical Corporation (SINOPEC) is working on biofuels in some regions of the country while also pursuing a strategy for advancing into the overseas market. The company has announced planned investment of $5 billion in Indonesia. In partnership with local company P.T Puri Usaha Kencana, SINOPEC will develop plantations of biofuel crops (palm oil and *Jatropha curcas L.*) at multiple locations in the province of Papua and on the island of Borneo, and plans to construct a biofuel refinery.

Within the country, China National Offshore Oil Corporation (CNOOC) is making large-scale investment in the island of Hainan as a cultivation base for *Jatropha curcas L.*. As an overseas investment project, it has partnered with Sinamas Group, a Chinese conglomerate in Indonesia, and is developing palm oil and cassava raw material. CNOOC will invest a total of $5.5 billion in this project.

(4) Initiatives of airline companies

As new entrants, airlines' start of initiatives regarding biofuel greatly excited the biofuel market. One after the other major airline companies announced plans to develop aviation biofuel, boosting the potential for expansion of the biofuel market.

Air New Zealand announced plans to conduct test flights using jatropha oil during 2008.[13] In February 2008, major British airway Virgin Atlantic Airways reported successful test flights using coconut oil-based jet fuel. Major aerospace equipment manufacturer Honeywell Aerospace has partnered with multiple companies, including Airbus and JetBlue Airways, to develop aviation biofuels made from algae and *Jatropha curcas L.*. Japan Airlines reported plans to conduct test flights in Japan using aviation biofuel derived from nonfood source biofuel, the first such test in Asia, during 2008 in partnership with Boeing Company and Pratt & Whitney.[14]It did not announce the

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13 Kyodo News (May 28, 2008): http://www.47news.jp/CN/200805/CN2008052801000824.html
14 http://press.jal.co.jp/ja/release/200806/000953.html

actual nonfood raw material to be used.

(5) Japanese companies

There are a number of *Jatropha curcas L.* plantation development ventures being run by Japanese companies (e.g. Nippon Biodiesel Fuel Co., Ltd., I S Corporation Ltd., and Japan Bio-Energy Development Corporation). The number of such companies has increased rapidly in the past few months. Most are developing plantations in Southeast Asia and Africa. The activities of each company are described on their homepages, and so details will be omitted here. In each case projects are small-scale or at the R&D stage.

At the same time, cultivation R&D is being conducted at a number of locations in Japan, including by Atlas Co., Ltd., in Okinawa and Kobe Tropical Agricultural Research Institute in the city of Sanda. While there is potential for local production for local consumption, it will be difficult to chief economic efficiency, since productivity cannot be expected to be as high as in tropical regions.

In the downstream market, numerous companies are reported to be conducting research and development on the use of jatropha oil. Among them, Yanmar Co., Ltd., established a biodiesel research facility in the Malaysian state of Sabah on January 31, 2008. It is conducting endurance tests of engines running on palm oil and non-food oils such as jatropha oil.

2.2 Status of cultivation and activities in different countries

(1) India

India was the first country to launch an effort to use *Jatropha curcas L.* as a biodiesel. In April 2003, the Committee on Development of Biofuels, which was established by the Indian government, announced the goal of reducing India's consumption of petroleum-based light oil by 20%. This goal pushed the cultivation of non-edible *Jatropha curcas L.* as biodiesel crop.

Actual *Jatropha curcas L.* cultivation projects, starting around November 2003, included a five-year cultivation plan supported by DaimlerChrysler and a plan to cultivate *Jatropha curcas L.* alongside 2,500 km of Indian railroads. After entering 2007, investment by foreign companies in India picked up, pushed by the problem of biofuels' competition with food. Britain's D1 Boils, Australia's Mission Biofuels, and other companies entered India and increased the level of initiatives.

There are seven kinds of nonfood oil crops that are candidates as biodiesel crops in India. Among them, *Jatropha curcas L.* looks promising, since it can be grown in wasteland. At present, the introduction of biodiesel in India is at the demonstration stage, but there are plans to expand the serviced regions and spread the introduction of biodiesel nationwide following enlargement of the supply capacity.

The National Biodiesel Mission implemented by the Indian government has been advanced in two stages. Phase 1 involves pilot projects conducted during 2006-2007 and the investment of 15 billion rupees (about $376 million USD) in the development of 400,000 ha of *Jatropha curcas L.* plantations. Phase 2 promotes autonomous development programs and calls for continuous expansion of the production capacity needed to achieve the goal of a 20% reduction in diesel consumption by fiscal 2012, centering on 43.13 million ha of identified unused land. However, while plans for the cultivation of *Jatropha curcas L.* have moved forward, the cultivated area has not expanded, since actual oil productivity was far less than expected. With the outlook on raw material procurement having fallen, the Indian government is groping for a future breakthrough to promote its National Biodiesel Mission.

(2) China

The Chinese government has started efforts to legislate the adoption of biodiesel and is moving forward with market preparation, including issues of supply, quality, and distribution. Initially, the adoption of biofuel in China was mainly centered on bio-ethanol. Since 2007, the adoption of biodiesel has been pushed forward seriously. At present, production of biodiesel using waste cooking oil is being undertaken on a scale of tens of thousands of tons in Fujian Province. In November 2007, standards for 100% biodiesel (B100) were announced, and standards for B20 fuel are being considered. Moreover, administrative regulations clearly stipulate that agricultural land for producing food can not be used to develop land for biodiesel crops.

Large-scale cultivation plans are being pushed forward in the provinces of Sichuan, Yunnan, Guizhou, Guangxi, Guangdong, and Hainan, which are provinces in southern China suitable to the cultivation of *Jatropha curcas L.*[15] as a biodiesel crop. The most distinguishing characteristic of the cultivation development of *Jatropha curcas L.* in China is the fact that it is being led by the three major state-run oil companies. The three companies are undertaking development and introducing capital in different regions where they have each been given preferential rights: CNPC in the provinces of Sichuan, Yunnan, and Guizhou; SINOPEC in Guangxi and Guangdong; and CNOOC in Hainan Province.

(3) Indonesia

In 2006, Indonesia announced the “Blueprint: Biofuel development as an emergency measure against poverty and unemployment from 2006-2025” with the aim of expanding employment in the country.[16] Within this blueprint, the government mapped out a plan for *Jatropha curcas L.* in which 500,000 people would be employed per year in 2010 to produce 7.5 million tons of *Jatropha curcas*

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[15] In China, *Jatropha curcas L.* is known by names such as *mafengshu* and *xiaotongzi*.

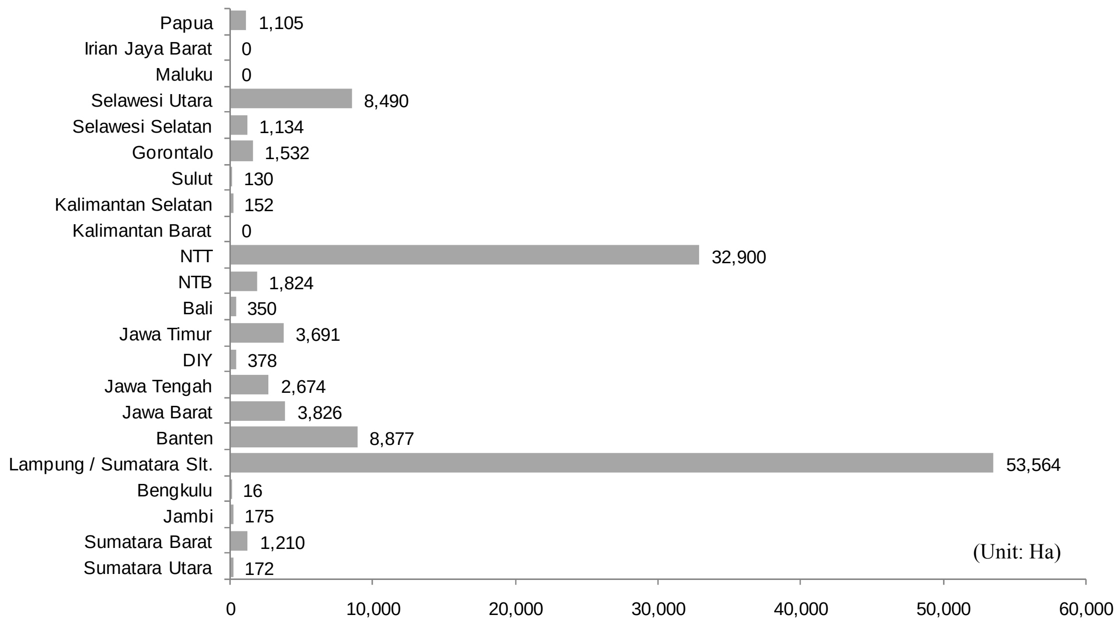
[16] “BLUE PRINT PENGEMBANGAN BAHAN BAKAR NABATI UNTUK PERCEPATAN PENGURANGAN KEMISKINAN DAN PENGANGGURAN”

L. oil (CJO) on 1.5 million ha of arable land and one million people would be employed per year in 2015 to produce 15,000,000 tons of CJO on 3 million ha of arable land. In addition, the plan clearly states a variety of development policies in related industries such as shipping and transportation, commercial trade, information and communications, and distribution.

During World War II, the Japanese military attempted to produce *Jatropha curcas L.* in Indonesia. At that time, it was difficult to procure the fossil fuel needed during war time, and so the Japanese military aid Indonesians cultivate *Jatropha curcas L.* across the country as an oil crop.[17]

Indonesian lore still says that the introduction of *Jatropha curcas L.* into the country dates back to the age of exploration and that it was cultivated during the period of settlement by the Dutch and Portuguese. Indonesian residents use the plant in folk medicine as an anesthetic and skin disease treatment. Nowadays, a great variety of jatropha grows wild with major differences existing between islands.

Figure 3 Area of *Jatropha curcas L.* cultivation in Indonesia (as of end of December 2007)



Source: Indonesia's National Biofuel Team, February 2008.

The Indonesian names for *Jatropha curcas L.* also differ by region. It is often called *jarak* or *jarak pagar*[18], but has different common names on each island and among each ethnic group. Generally, *Jatropha curcas L.* is planted by farmers in rural communities as a fence around their houses. Oil is extracted from the seeds and used as a ingredient in medicines and a fuel for lighting and cooking.

[17] It is well known that the anecdote concerning the Japanese military's utilization of jatropha during the war appears in junior and senior high school textbooks, but concrete documents have not been confirmed.

[18] Pagar means fence.

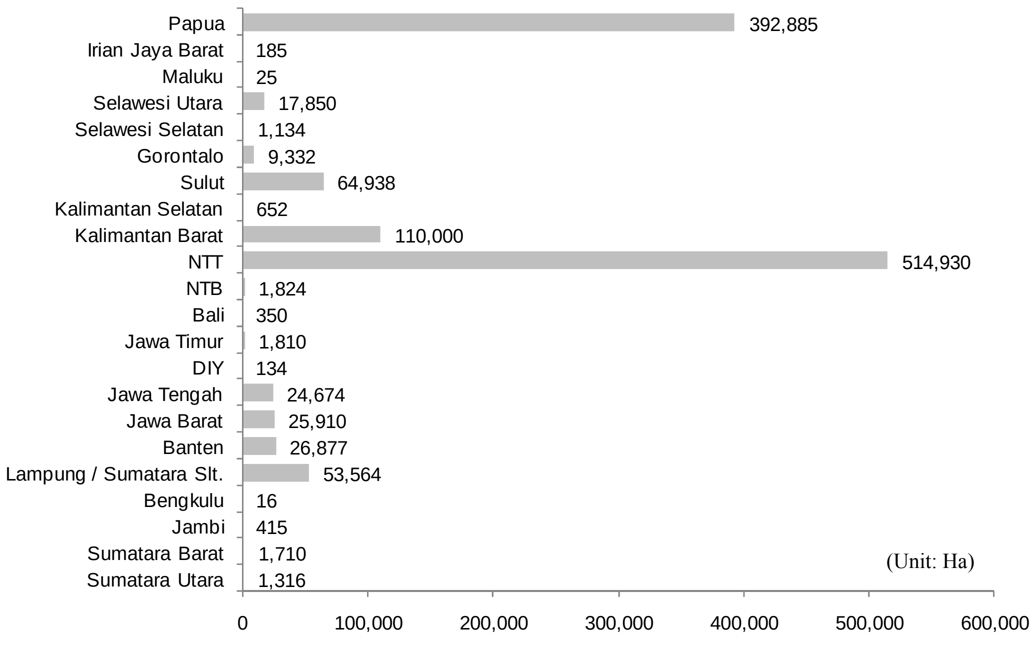
The cultivation of *Jatropha curcas L.* as a biodiesel crop appears to have been started by a company called P.T. Agrila in 2003 on the island of Lombok. *Jatropha curcas L.* began attracting attention in Indonesia when this company started cultivating it to provide CJO for experiments it conducted in 2003. Lombok experienced a cultivation boom when oil prices soared in 2006. The boom then spread from Lombok to Java, Sulawesi, and across the country.

According to an announcement by the Indonesian government, an area of 94,000 ha had already been planted nationwide by the end of December 2007. However, the accuracy of the cultivated area indicated in this announcement has been questioned, and in many cases CJO is not being produced. It is thought that the current area of *jatropha curcas L.* cultivation in Indonesia is far less.

On the other hand, the Indonesian government has set ambitious goals. According to an announcement by the National Biofuel Team, the government wants to cultivate 15 million ha by 2015, and has decided cultivation areas for each province depending on the situations of implementation. Looking at the breakdown by province, the targets for the area of cultivation are highest for NTT and Papua. Together the targets for these two provinces — 515,000 ha (41%) for one and 393,000 ha (31%) for the other—account for 72% overall. Other centers for cultivation development besides these are islands of Kalimantan and Sumatra.

At present, the Ministry of Agriculture is developing base farms in each region, providing cultivation guide and centered on base farms, providing good variety seeds, and otherwise making an effort to expand the cultivated area.

Figure 4 Targets for area of *Jatropha curcas L.* cultivation by province



Source: Indonesia's National Biofuel Team, February 2008.

(4) Myanmar

Myanmar has been placed under sanctions by the international community, making it economically difficult for the country to procure oil and other fossil fuels from the international oil market. Accordingly, the military government is pushing the autonomous development of fuel within the country. In particular, it is emphasizing the development of *Jatropha curcas L.*, which is a biodiesel crop. The country's current goal is to cultivate 2.3 million ha by 2010.

There are reports that the military authorities are forcing farmers to switch from traditional crops to *Jatropha curcas L.*. On the other hand is the perspective that domestic demand will not spread easily, since technology is for utilizing CJO, the product of *Jatropha curcas L.* are not widely diffused. While there are also reports of exportation to the international market, this possibility is thought to be low, since Myanmar has a chronic deficiency of petroleum-based fuels. However, since the government can sell CJO at compulsory controlled prices, it is possible that adoption will advance in the future. At the present, the scale of production in Myanmar is not known, and it is thought that technology for utilizing CJO is most likely crude.

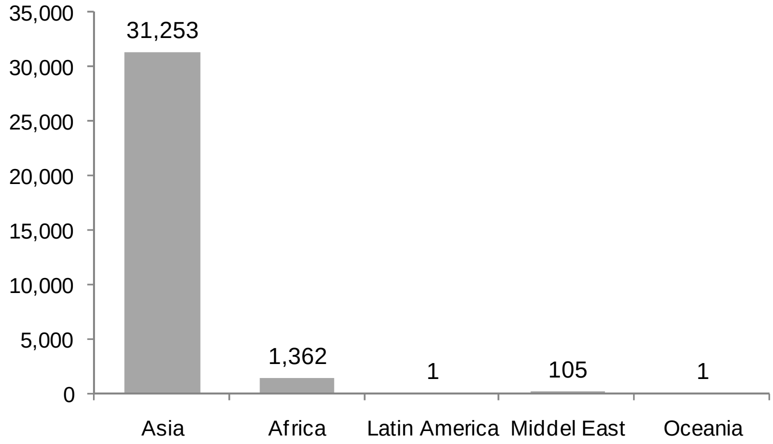
2.3 Each country's potential to supply *Jatropha curcas L.*

The International Jatropha Organization has announced figures that include cultivation plans and projections for each part of the world over the next 10 years. These projections claim that in 2017 there will be 32.72 million ha of land cultivated with *Jatropha curcas L.* worldwide, producing 160 million tons of seeds. A distinction of these projections is that 95.5% of the total production (156 million tons) will be concentrated in Asia. According to the International Jatropha Organization, 31.25 million ha of land in Asia will be developed over the next 10 years for *Jatropha curcas L.* cultivation. The development potential for *Jatropha curcas L.* is especially high in India, China, and Indonesia. However, these estimates only show the potential if the area of unused land announced mainly by each country's government is planted with *Jatropha curcas L.*; they do not specify actual cultivation plans. The governments of some countries—namely, Indonesia, India, and Myanmar—have set clear cultivation targets and are taking action to promote achievement of those targets as part of national energy policy.

Within the International Jatropha Organization's projections in Asia, the cultivation plans of China, India, Indonesia, and Myanmar stand out. The central governments of India, Indonesia, and Myanmar in particular have implemented measures clearly aimed at expanding the cultivated area as part of their energy policies. There are great expectations that these moves will lead to the solving of social problems faced by developing countries, including rural development and poverty, besides the development of domestic fuel supplies.

Figure 5 Projected area of *Jatropha curcas L.* cultivation in each region in 2017

(Unit: 1,000 ha)



Source: Prepared by the International Jatropha Organization.

The expansion of *Jatropha curcas L.* cultivation by 2017 is expected to reach 12.7 million ha in China, 11 million ha in India, 4.5 million ha in Indonesia and 2.83 million ha in Myanmar. Although the area of cultivation in Thailand, Malaysia, the Philippines, Cambodia, and Vietnam is small, each of these countries' governments have already started considering adoption and are expected to announce *Jatropha curcas L.* cultivation plans in the near future. Thus, the area in Asia cultivated with *Jatropha curcas L.* is anticipated to continue expanding in the future.

Figure 6 and figure 7 shows the results of calculating the yield based on the cultivated areas, assuming 5 tons of seeds are produced per hectare. Thus, in decreasing order the annual production of *Jatropha curcas L.* oil (CJO) in Asian countries will be 19.05 million tons in China, 16.5 million tons in India, 6.75 million tons in Indonesia, and 4.25 million tons in Myanmar.

Figure 6 Projected area of *Jatropha curcas L.* cultivation in leading Asian countries in 2017

(Unit: 1,000 ha)

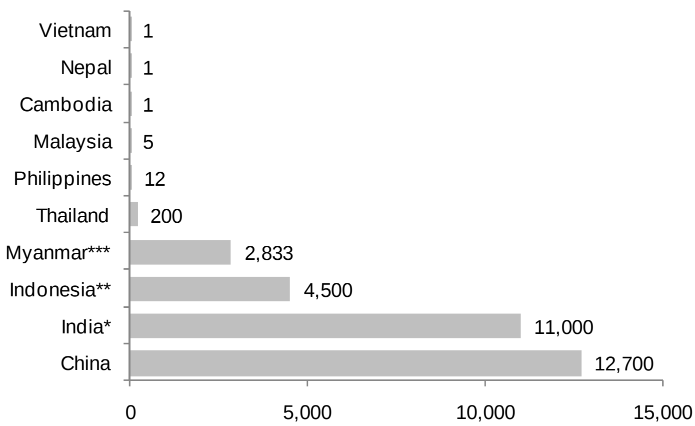
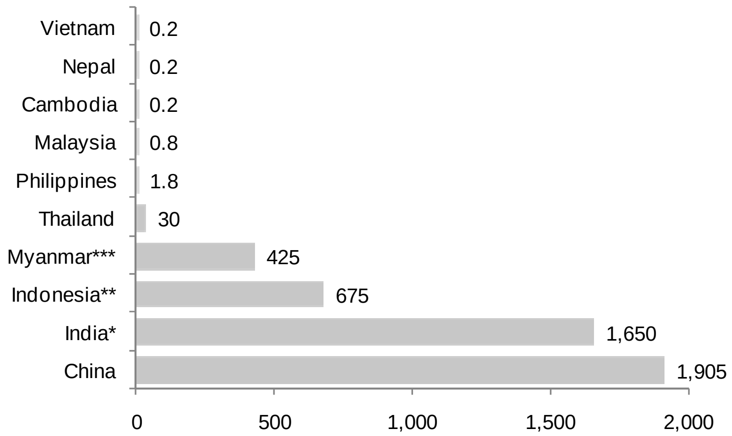


Figure 7 Projected production of *Jatropha curcas L.* oil in leading Asian countries in 2017

(Unit: 10,000 tons)



Note: Figures 5, 6 and 7 were prepared based on the area of *Jatropha curcas L.* cultivation announced by the International Jatropha Organization and the projected seed production. The actual cultivation plans announced by the governments of India, Indonesia, and Myanmar taken into account, with the production projections being estimated by the author. The national plans are:
* National Program on Jatropha, April, 2003 (India)
** Blue Print of biofuel, 2007 (Indonesia)
*** National Jatropha Programme (Myanmar)

Source: International Jatropha Organization. Prepared by estimation by the author.

3. Issues with the development of *Jatropha curcas L.* as a biofuel

3.1 Productivity

Within the commercialization of *Jatropha curcas L.*, productivity generates the most controversy. The productivity curve for *Jatropha curcas L.* as a plant is not well understood at present and actual data having reached the production peak is unclear. The productivity per hectare given in the currently widespread information ranges from 3-15 tons of seeds, which is a gap of some fivefold. The author understands that productivity will vary depending on the cultivated region, climate, soil quality, management, and other conditions, and merely wishes to point out that at the very least productivity curve data for *Jatropha curcas L.* as a crop has not been established.

With a dearth of actual empirical evidence, one does not know which data show correct productivity. What is most evident is that there are hardly any commercial plantations, at least in Asia, where plants have been growing for five or more years. Information that was distorted during *Jatropha curcas L.*'s initial research and development stage as a result of the market's heady expectations on nonfood biofuel crops has spread widely. This point needs to be considered seriously when planning investments, since it can directly impact cash flow.

Table 4 shows the productivity data released by different research institutions. The data from Bogor Agricultural University is the most valuable reference as real data, since it was collected from the yields obtained from cultivation on an actual research plantation. However, only two years worth of data has been collected from this plantation, and so productivity will have to continue to be observed in the future. Daimler released results, on an oil basis, for its five years of research in India but did not make clear an actual production curve. The reliability of results released by Indonesia's Ministry of Agriculture is lacking, since they are not actual data and their basis is unknown.

Table 4 Productivity data released by different organizations and companies

	Year	Bogor Agricultural University (1)		Ministry of Agriculture, Indonesia (2)			Daimler Chrysler
		INDOCEMENT Research Plantation	Caiwi Research Plantation (2 ha)	IP-1	IP-2	IP-3	Indian Research Plantation
		Old limestone mining site	Agricultural land	Unknown	Unknown	Unknown	Infertile land
Seeds (kg)	1st	200	600-800	1,100-1,500	2,000-2,500	-	
	2nd	± 500	± 1,700	-	-	-	
	3rd	-	-	-	-	-	
	4th	-	-	-	-	-	
	5th	-	-	4,500-5,000	6,000-7,000	8,000-10,000	
Oil (kg)	Assuming an oil extraction rate of 30% in the fifth year			1,350-1,500	1,800-2,100	2,400-3,000	1,000

Sources: (1) Prepared based on an interview with the Surfactant and Bioenergy Research Center (SBRC) of Bogor Agricultural University.
(2) Indonesian Center for Estate Crops Research and Development Ministry of Agriculture (2007). Prepared based on data released by Indonesia's Ministry of Agriculture, but thought to be estimated data, since nearly all of it has not been substantiated.
Note: IP-1, IP-2, and IP-3 are the names of *Jatropha curcas L.* varieties.

3.2 Production cost and price

(1) Production cost

Table 5 shows the production cost of crude palm oil in Malaysia released by the Malaysian Palm Oil Board (MPOB) and the production cost of crude *Jatropha curcas L.* oil (CJO) released by Professor Erliza Hambai of Indonesia's Bogor Agricultural University. At $231 per ton, the production cost of CJO is slightly less than that for crude palm oil, which is $290 per ton. Although the average production costs for these crude oils do not differ greatly, the main difference between them is the operations costs during the period of production. The management costs for palm oil during the period of production is nearly 4 times that for *Jatropha curcas L.*: $1,014 per hectare per year versus no more than $250 for *Jatropha curcas L.*. However, the productivity of palm oil (per-hectare production volume) ends up being overwhelmingly greater than that for *Jatropha curcas L.*.

Table 5 Comparison of production costs for *Jatropha curcas L.* versus palm oil

Factor	*Jatropha curcas L.*		Palm oil	
1. Preproduction cost (USD/year)				
- Average per hectare	980.94	USD/hectare	817.49	USD/hectare
- Annual average*	39.24	USD/year	32.70	USD/year
- Average yield**	7.85	USD/ton of seeds	1.82	USD/ton FFB
2. Production cost (USD/year)				
- Average per hectare	249.92	USD/hectare/year	1,014.27	USD/hectare/year
- Average yield	49.98	USD/ton of seeds	56.35	USD/ton FFB
	199.93	USD/ton of crude oil	281.74	USD/ton of crude oil
- Labor force needed	105	People/day	41	People/day
3. Total cost (USD/year)				
- Average per hectare	289.16	USD/hectare/year	1,046.97	USD/hectare/year
- Average yield	57.83	USD/ton of seeds	58.16	USD/ton FFB
	231.32	USD/ton of crude oil	290.82	USD/ton of crude oil

Notes: * The period of productivity was set at 25 years for both crops.
** Calculated based on an annual average of 5 tons/hectare/variety for *Jatropha curcas L.* and an annual average of 18 tons/hectare/FFB for palm oil. Production volume of crude oil calculated based on an oil content of 25% for *Jatropha curcas L.* and an oil content of 20% for palm oil.
Source: Data released by the Malaysian Palm Oil Board (MPOB) was used for the production cost of palm oil and the production cost estimated by Professor Erliza of Bogor Agricultural University was used for *Jatropha curcas L.*.

(2) Price

As of September 2008, *Jatropha curcas L.* seeds are trading in Indonesia at 2,500-3,500 Rp/kg (about 29-41 yen[19]/kg). Assuming an oil extraction rate of 25%, it takes 4 kg of seeds to produce 1 liter of CJO. In other words, the price is approximately 117.6-164.7 yen/liter. Prices fluctuate violently, since the market for *Jatropha curcas L.* seeds is not well formed, making it difficult to make simple comparisons between *Jatropha curcas L.* oil and fossil fuels.

At present, the actual volume of *Jatropha curcas L.* seeds being traded in the market is quite small. With cultivation expanding everywhere at the moment, demand for seeds for cultivation is growing, which is taking seeds for oil production out of circulation. It is highly possible that this phenomenon will continue until the rate of expansion of cultivated area slows down (about 1-2 years), making it conceivable that crude jatropha oil (CJO) will not appear on the market for a while. The price of seeds for planting has jumped, reaching 1,500-5,000 Rp/kg in Indonesia. Including other costs such as about 400 Rp/kg for oil pressing and approximately 100 Rp/kg for transportation (depending on the distance) pushes the price even higher.

3.3 Establishing cultivation in management techniques

Efforts to solve issues such as how to increase *Jatropha curcas L.* yields and improve harvest

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[19] Exchange rate: 1 yen = 85 rupiah

methods are continuing, but there are still great risks at present regarding the use of *Jatropha curcas L.* as a raw material for automobile biofuel. However, with its ability to be cultivated in wasteland and its non-competition with food production being highlighted, *Jatropha curcas L.* is very attractive as a biodiesel crop, driving the search for solutions by entrepreneurs, new businesses set up by major companies in the farming, oil, and automobile industries, and research projects conducted by government organizations.

The biggest challenge right now is raising the productivity of *Jatropha curcas L.*. According to the results of special research teams in different countries, the productive capacity of *Jatropha curcas L.* seeds can be expected to reach 5 tons/ha. However, *Jatropha curcas L.* fruit is small and the ripe fruit will not in same time, making harvesting a difficulty with plantation cultivation. While *Jatropha curcas L.* can be used for everyday fuel in rural villages with small-scale cultivation, mass production is difficult because there is no system for collecting the dispersed seeds. Whether or not techniques for managing *Jatropha curcas L.* as a plantation crop can be established will decide the fate of any future *Jatropha curcas L.* industry. On the other hand, a labor force is needed to harvest the fruit by hand, and so developing countries are planning cultivation as a means of expanding employment.

3.4 Competition with other oil crops

Jatropha curcas L. is introduced as a nonfood oil crop and emphasis is placed on the point that it has no adverse effect on food production, leading to the understanding that it is not in competition with other oil crops. In truth, *Jatropha curcas L.* seeds are poisonous and are used as medicine and fuel for everyday use. The residue remaining after pressing oil from *Jatropha curcas L.* seeds is protein-rich, creating the potential for a high utility value. But, little research has been conducted on the toxicity of *Jatropha curcas L.* seeds, and so use of the residue is limited to fuel and fertilizer. It should be noted that a non-toxic *Jatropha curcas L.* variety has been developed in Mexico using genetic engineering.

It is also commonly known that the essential management conditions for *Jatropha curcas L.* are not that harsh, such as its ability to grow in wasteland without much water. However, water and fertilizer would be important for mass production on a commercial basis, and so most companies making an investment use farmland with better conditions to develop plantations. In this case, if the producing area for *Jatropha curcas L.* expands, eventually a changeover from existing crops will take place, making it unlikely that competition with food can be avoided.

3.5 Debate about toxic components

Toxic components are found throughout the entire *Jatropha curcas L.* tree. In all regions it is cultivated around gardens as a hedge to keep domestic cows, sheep, horses, and other animals out of the garden. It has been confirmed have a long-established use as a traditional medicinal plant among indigenous peoples in Southeast Asia. The sap is used as a piscicide (fish poison) in traditional river fishing.

Current research has identified a toxalbumin called curcin in the seeds, fruit, sap, and other parts of *Jatropha curcas L.* as a phytotoxin in this plant. Most of the curcin is contained in the protein inside the seed. Curcin is less toxic than the ricin from the castor oil plant (*Ricinus communis*).[20] Curcin is not present in jatropha oil, since it is not lipid soluble, but it is contained in the seeds and seed cake.

Another worry is phorbol esters, which are carcinogens. Sufficient research has yet to be conducted on the phorbol esters contained in *Jatropha curcas L.*, and it is still not known what kind of effect they have. Thus, more verification is needed.

Jatropha curcas L. is not used to produce edible oil, and so the chances of human consumption are low. Nevertheless, there are many reports of mistaken ingestion as a seed, mostly by children.

Table 6 Poisonous components of *Jatropha curcas L.*

Component	Unit	Value (%)	
		Seed	Seed cake*
Trypsin inhibitor activity	mg trypsin	18.4 - 27.5	21.1 - 26.5
Saponin (as diosgenin)	%	1.8 - 3.4	2.0 - 3.4
Phytate (as phytic acid equivalent)	%	6.2 -10.1	8.9 - 10.1
Lecithin activity (curcin)		0.85 - 6.85	51 - 102
Phorbol esters	mg/g kernel	0.87 - 3.32	0.11 - 2.70

Source: Wink et al (1997) in Gubitz et al (1997)*, Makkar and Becker (1997) in Gubitz et al (1997).

4. Conclusion

Clearly, *Jatropha curcas L.* has huge potential as an oil crop. At present, a lot of research is moving forward in different countries toward commercial production, including research on cultivation techniques, breed improvement, management techniques, and production technology. As mentioned above, however, the productivity curve for seeds is unclear, and in many cases cultivation is going ahead even while the information on yields, suitable land for cultivation, and other matters is inaccurate. Moreover, hasty investment activities could ultimately hinder the steady expansion of the *Jatropha curcas L.* market, since the properties of *Jatropha curcas L.* oil, processing technologies, and downstream application technologies such as detoxification have not yet been established.

Right now, the most important challenges are to first of all obtain accurate information on upstream production, improve breeds, and establish cultivation techniques. All crops have their own

[20] Kawazu, Kazuyoshi. “Piscicidal Plants in Southeast Asia and Their Active Principles,” page 169.

characteristics. Some crops such as palm oil, rubber, tea, soybeans, corn, and sugar cane can be grown on expansive plantations whereas others such as pepper, coffee, cocoa, and fruit trees are managed on small-scale farms. With current know-how it is probably almost impossible to develop huge plantations of *Jatropha curcas L.*. Developing *Jatropha curcas L.* into a plantation crop would be a long-term effort requiring starting with small-scale cultivation and validating management techniques while gradually increasing the scale of production.

The process used to develop palm oil is the best reference. The initial development of palm oil was on a much smaller productivity and cultivation scale than nowadays and was a time when palm oil was not that attractive as an investment. The current scale of palm oil production is, indeed, the result of half a century of R&D. As a new oil crop, *Jatropha curcas L.* is still in the initial development stage and will need a slightly longer period of demonstration in order to spread as a major raw material on the fuel market.

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