

Jatropha curcas

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This paper reviews the current status of studies on *Jatropha curcas* in China. *Jatropha curcas* has been grown in China for more than 300 years. It is mainly distributed in the south east from the Yunnan-Guizhou Plateau to the hot and dry Three-River Valley with hot monsoon climate and the southeast in the provinces of Fujian, Guangdong, Guangxi, Hainan and Taiwan along the coast. The regions where it occurs have annual rainfall >500 mm and average annual temperature greater than 19 °C. It occurs on a wide range of soil regimes in these regions. In China the *Jatropha* usually blossoms and bears fruits only once a year, but there are also instances of two or more croppings per year. In some small but high yielding pilot areas, dry fruit output is reported to be 9,000–12,000 kg per ha,

whereas in large plantings the output averages only about 1,800 kg per ha. In order to contribute to sustainable production of *Jatropha*, further studies focused on different ecotypes, improvement of seed quality, plantation techniques, cropping and fruiting characteristics, and harvest and post-harvest handling of seeds are required. More research on biomedicinal potential of various parts of the plant and more information on the actual and potential markets is needed to realize the full potential of *Jatropha*.

Keywords · Biodiesel ·
Botany · China · Distribution · *Jatropha curcas*

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The exploitation of bioenergy has recently attracted much scientific and commercial attention as a means of addressing the looming energy crisis. China is already the second largest buyer of crude oil worldwide, and the demand for oil is increasing due to its fast growing economy. In the context of the search for indigenous sources of renewable liquid fuels, *J. curcas* (Peanut) has received increasing interest since the beginning of the 21st century (Dong 2004; Fei et al. 2005; Lin 2004; Min et al. 2005; Su et al. 2006; Tian et al. 2005; Xin 2005).

Jatropha curcas is a multipurpose shrub or small tree belonging to the family of Euphorbiaceae with

man attributes and multiple uses. In many countries, it has been used to prevent or control erosion, reclaim land, and for live fencing. Recently, it is also being planted as a commercial crop, but it grows mainly in the wild. The plant has gradually attracted increased interest for biodiesel, and increasing farmer income. In China, there may be a basis for emerging commercialization of jatropha. A more comprehensive evaluation of its multifaceted potential is needed to bring the expected economic, social and environmental benefits for the country as a whole.

This paper reviews jatropha resources, distribution, biology, and ecology. It is hoped that the state-of-the-art information provided here will stimulate research and development leading to more intensive, efficient, and sustainable utilization of jatropha.

Provenances and distribution

Jatropha curcas (Piscifera nut) is a shrub or small tree belonging to the family of *Euphorbiaceae*. There are 175 species of jatropha plants in the world (Anonymous 1996), of which five are present in China (Anonymous 1996). These are *J. curcas* L., *J. podagrica* Hook, *J. multifida* L., *J. gossypifolia* L. and *J. integerrima* Jacq. In China *J. curcas* L. has many alternate names, for example Xiaotongzi (Pan-jiang), Shuhuasheng (Hainan), Huang hongshu (Guangdong) and Jiahuasheng (Guangxi). This plant has mainly been developed as a bioenergy plant, whereas *J. podagrica* Hook and *J. integerrima* Jacq are mainly promoted as ornamental plants (Anonymous 1996; Shui 2005).

The origin of jatropha in China is unknown. It is reported that this plant has been grown in China for more than 300 years and it has become naturalised. *J. curcas* is widely grown in Central and South America, Southern Asia, and Central Southern Peninsular Asia including countries such as Myanmar, Thailand, Laos, Cambodia, Malaysia and India (Anonymous 1965, 1996; Shui 2005). In China, this plant is distributed from 98°6' to 121°31'E to 18°14' to 27°55'N. There are distinctive concentrations of occurrence of jatropha in the southwest and the southeast of the country. Jatropha occurs from the Yunnan-Guizhou Plateau to the dry-hot valley of

Three-Rivers (Nu River, Jinshajiang River, Lancang River). This area includes the west of Panjiang Prefecture in Sichuan, most of Yunnan province and the southwest of Guizhou province. In Sichuan province, jatropha is found in Panjiang, Yanbian, Mian, Ningnan, Dechang, Xichang, Huili, and Jiangyan counties (Li et al. 2006b). In Yunnan province, jatropha is widely grown in Chuxiong Yi Autonomous Prefecture, Dali, and Honghe, which are located around the Three-River Valley in the west and southwest of Yunnan (Zhang et al. 2001a). Jatropha is also present in the southwest Guizhou province, in the dry-hot valley of Nanpan River, Beipan River and Hongshui River (Fig. 1). The vertical distribution range of jatropha consists of piedmont, ravines, slopes and alluvial plains, at an altitude of 600–1,800 m (Zheng 1998). Jatropha is mainly present in areas below an altitude of 1,600 m, with the highest altitude being 2,000 m (Zheng 1998).

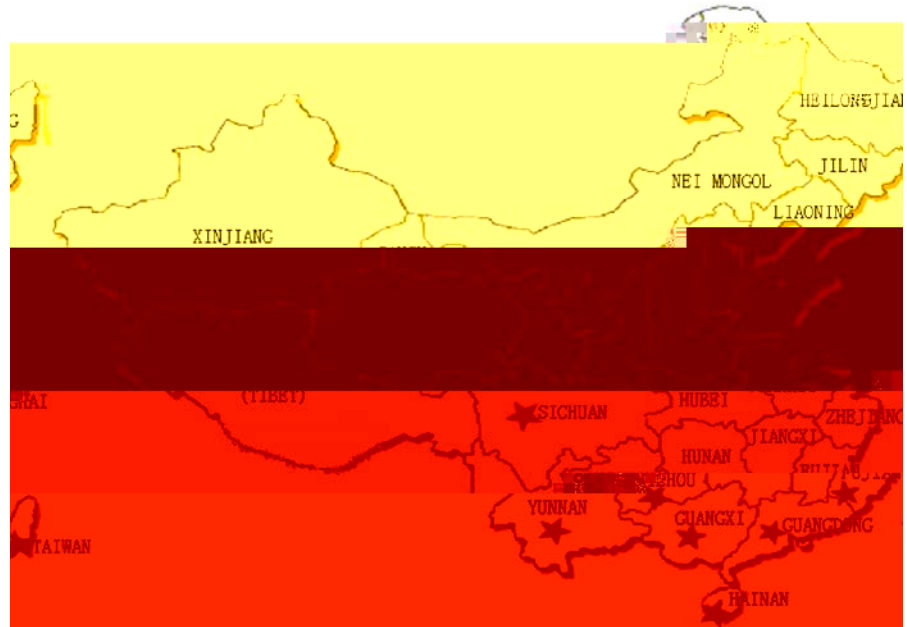
In the Southeast region, jatropha grows in Fujian, Guangdong, Guangxi, Hainan and Taiwan along the southeast coast (Anonymous 1998). These areas have tropical and subtropical maritime climate. The vertical distribution of jatropha is 50–1,500 m altitude. Jatropha is common in Hainan Island.

In December 2005, the Sichuan Provincial Approval Board for Forest Breeding identified two improved clones of jatropha: Chen Fang in Sichuan (CSC) High-toleic 1 and CSC High-oil 63 (Huang and Han 2006; Wu et al. 2008). The plants of the former clone grow to a height of 5 m, have smooth bark, and a large number of thorns. The average toleic protein content of seeds is 4.2%, which is 30.4% higher than the parent plant. It is relatively tolerant to drought and pests- and diseases and can be grown on poor and degraded soil. This provenance normally grows below elevations of 1,800 m in the basins of Yalong River and Jinshajiang River, and below 1,600 m in branch-valley areas in Huili county of Liangshan state and Yanbian county of Panjiang Prefecture. It could be introduced into Yunnan, Guangxi and Guizhou, where the climate is similar to the above areas.

The CSC High-oil 63 plant has small, sub-rounded fruits, with thin capsule sheath and seedcoat. The kernel is moderate and plump, with oil content of 62–65%, which is 15.6% more than the parent plant (Huang and Han 2006).

The toleic acid of *J. curcas* is attributed to the presence of phorbol esters (Makkar et al. 1997). It

1 Distribution of *Jatropha curcas* in China (the stars indicate provinces where *Jatropha* occurs)



ould be interesting to compare the phorbol ester content in the kernels of seeds from CSC High-oil 1 and CSC High-oil 63 clones.

Morphology

Jatropha curcas is a deciduous shrub or small tree that grows to a height of about 5 m. It has smooth bark, sturdy branches, and thick paper leaves. The leaves are 8 to 18 cm wide, shiny and glabrous, with e liguous and pilose stipules. The petiole is 10–16 cm long. The inflorescence is monoecious, but the individual flowers are unisexual. The male flower has 5 sepals, 5 petals and 10 androeciums. The petals are lanceolate and twice the length of sepals. The female flower has no petals. The fruit of *J. curcas* is a capsule, 3–4 cm long and 2.5–3.0 cm wide. The immature capsule is subsphaeroidal and green turning to yellow and later to dark brown when ripe. The capsule develops cracks when fully dried. The seeds, 1.5–2.0 cm long and 1.0–1.2 cm wide, are rich in oil, elliptical, and black (Anonymous 1996, 1972).

Biological characteristics

Root

Jatropha has well developed roots. The taproots are long and prominent and the lateral roots are also well

developed. In loose soil, the taproot can be twice the length of the aerial portion. When *Jatropha* is 18–25 cm tall, the taproot may be 40–50 cm long with 6–10 lateral roots that are 30–45 cm long (Meng Ye, unpublished observations). Li et al. (2006a, b) isolated 57 strains of endophytic fungi from the roots and stem of *Jatropha*, among which 2 strains are antagonistic to *Colletotrichum gloeosporioides*.

Stem

Under hot-dry conditions as in Panhihua city, the annual height increment of the field growing *Jatropha* plants is about 10 cm in the first and second year, and 20 and 40 cm in the third and fourth year, respectively. After harvest the plant begins to grow rapidly. In the case of planned afforestation, the plant can grow 40–50 cm tall in the first year and above 100 cm in the second year. In the middle or the last ten days of February when the temperature is near 15 °C, the plant begins to sprout and grow. In November, the leaves senesce. The branches, trunk, and roots of *Jatropha* are succulent. Diseases and insect pests are seldom observed in the field trees (Meng Ye, unpublished observations).

Flowering and fruiting

Plant flowering and breeding characteristics were reported by Chang-wei et al. (2007). Fruit is produced

through apomies but not wind pollination. *Jatropha* is self compatible, but normally shows outcrossing and requires pollinators. A tendency to promote enogamy and minimize geitonogamy is also evident. *Jatropha* begins to bear fruits 3 to 4 years after being planted in the dry regions where it normally occurs. It will reach the full fruit period in the fifth year. Usually the plant bears fruits once a year. In Panhihua district of Sichuan, it flowers in April and the fruits ripen in September to October (Kun et al. 2007; Li et al. 2006a, b). In the sunny and hot areas such as Xishuangbanna and De Hong of Yunnan province, the plant can blossom twice a year with a second flowering in October, the fruits of which mature in February next year (Wu and Chen 1988). With sufficient water-supply, *Jatropha* blooms throughout the year (Meng Ye, unpublished observations).

It is estimated that in some small but high yielding areas with fertile soil and sufficient water-supply, dry fruit output is as high as 9,000–12,000 kg per ha (yield from small areas up to one hectare), whereas in large field growing areas, the output is only about 1,800 kg per ha (Zhang et al. 2001a). However, the former figure appears to be very high and difficult to attain under routine plantation conditions (Meng Ye, personal observations).

Seed characteristics

The oil content of seed kernel from 11 counties varied from 51.3 to 61.2% (Li et al. 2006b). Seed (kernel and shell) collected from other regions of China had an oil content of 31.4–37.6% (Wang et al. 2008). These values are similar to those obtained for seeds from other regions (Table 1). In Yuanmou county of Yunnan, the oil content of *Jatropha* seed kernels was 55.5% (Li et al. 2006b). The total amino acid content of kernel meal (defatted kernels; kernel is the shell-free white portion of the seed) was relatively high, up to 47.6% of the total weight. Contents of essential amino acids in *Jatropha* are higher than those of many commonly used feed ingredients (Makkar et al. 1998; Zhang et al. 2001a, b; Table 2). The non-protein nitrogen in *Jatropha* meal formed only 9.0% of the total nitrogen in the *Jatropha* meals suggesting a high level of true protein (Makkar et al. 1998). The high protein efficiency in rats and the rapid growth observed in shifed non-toxic *Jatropha* meal (Makkar and Becker 1999)

1 Seed Characters of *Jatropha curcas* from 11 counties in south east China

Parameters	Range
100-seed weight range (g)	48.2–72.3 (49.0–86.0)
Average 100-seed weight (g)	56.9 (0.64)
Percent kernel weight of seed	61.5–68.9 (53.9–64)
Oil content of kernels (%)	51.3–61.2 (43.0–59.0)

Source: (Li et al. 2006b; Zhang et al. 2001a)

Values in the parenthesis are of 18 provenances from different countries (Makkar et al. 1997)

suggested that the protein quality of *Jatropha* kernel meal is very high.

Temperature, moisture, and soil

Luo et al. (2005a) studied the cold injury and cold-resistance properties of *Jatropha* seedlings under different temperatures (25, 12, 8 and 4 °C) for time periods of 1, 2, 3 and 4 days. It was observed that temperatures <8 °C resulted in significant injury to seedlings. Temperatures >12 °C had no significant negative effect. Young seedlings died when exposed to frost. Liang et al. (2007) demonstrated the role of photosynthesis-related proteins and hydrogen peroxide scavenging in the cold response mechanism of *Jatropha* seedlings. Zhang et al. (2008) linked a betaine aldehyde dehydrogenase gene from *Jatropha* to environmental stress; the expression of this gene was found to increase in leaves in response to drought, heat and salt concentration.

Jiang et al. (2004) compared drought-tolerance of 10 tree species and showed that *Jatropha* had the greatest drought tolerance. Water stress did not change protein content in the vegetative organs and seeds (Chen et al. 2003). *Jatropha* grows under a wide range of soil regimes ranging from alluvial soil to red lateritic soil. It grows well in deep, fertile and loose soil, such as those in ravines (Meng Ye, unpublished observations). However, *Jatropha* does not tolerate sticky, impermeable, and waterlogged soils.

Sunlight

Jatropha requires sufficient sunshine, and cannot grow well under shade. Zhang and Fan (2005) investigated the photosynthetic response of *Jatropha* irrigated in such a way as to maintain soil moisture in the pots at



Amino acid concentrations of *Jatropha curcas* seeds

Amino acid	Seed meal (%)	Kernel meal (%)	Amino acid	Seed meal (%)	Kernel meal (%)
Threonine	0.87	1.92	Serine	1.14	2.59
Methionine	0.37	0.87	Glutamine	3.83	8.73
Isoleucine	1.04	2.14	Glycine	1.06	2.29
Leucine	1.66	3.68	Alanine	1.15	2.49
Lysine	0.87	1.86	Cysteine	0.32	0.88
Phenylalanine	1.01	2.28	Tyrosine	0.33	1.46
Arginine	1.09	6.07	Histidine	0.55	1.24
Valine	1.14	2.41	Proline	0.93	2.03
Aspartic acid	2.23	4.68	Total	20.40	47.62

Source (Zhang et al. 2001b)

Seed meal, solvent extracted seed cake. The seed cake is produced when whole jatropha seeds are pressed for oil extraction in an expeller (screw press)

Kernel meal, solvent extracted jatropha kernel

65% or under dry condition where the soil moisture in the pots was 45%. With irrigation, the light compensation point of photosynthesis and light saturation point were 163.41 and 1,046.73 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The diurnal variation in the rate of photosynthesis showed a typical peaked curve. Under the dry condition, the light compensation point and the light saturation point of photosynthesis were 193.82 and 697.08 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively.

Seedlings

A germination of 80–90% has been obtained for seeds collected during October to December in Panhihua. The seed had been dried in shade, and stored dry indoors. The seeds retained germinating ability for >2 years (Deng et al. 2005). *Jatropha* planting material is mainly raised through seedlings currently.

Cuttings

Cuttings can be generated from one or two-year-old cuttings with 15–20 cm length. The proper time for raising cuttings is from the last ten days of August to the first half days of September in Guihou. Cuttings may be covered with an arched roof made of plastic

film, in which the temperature should not exceed 30°C. Rooting begins after 30–45 days of planting, and the generation rates from cuttings range from 50 to 80% (Li 2005). Roots of the cuttings are not as robust as those of the seedlings.

Tissue culture

The explants of hypocotyl, leaf blade and petiole from *Jatropha* were cultured on Murashige-Skoog (MS) medium with indole-3-butyric acid (IBA) and 6-benzyladenine (BA) for induction of callus (Lu et al. 2003; Wei et al. 2004a). The most suitable combination for shoot regeneration from callus was MS medium with 0.1 mg l^{-1} IBA and with 0.5 mg l^{-1} BA. Results obtained elsewhere showed that maximum shoot generation was attained in an MS medium with 1 mg l^{-1} IBA and 3 mg l^{-1} BA (Shrivastava and Banerjee 2008). Regenerated shoots could be rooted on growth regulator-free MS medium and could be transplanted in soil after simple hardening for several days (Lu et al. 2003). Regenerated plants with well-developed shoots and roots were successfully transferred to greenhouse, and the survival rate was 81.6% (Lu et al. 2003). Recently, use of additives such as arginine in addition to IBA and BA into the culture medium was reported to result in 100% survival of tissue-cultured *Jatropha* plants (Shrivastava and Banerjee 2008).



Silviculture

Jatropha can be used for afforestation when depth of the soil is >30 cm. *Jatropha* performs well when planted for landslide protection along slopes (Chen and Zheng 1987; Yang 2006). The mean annual temperature of the silvicultural locations needs to exceed 19 °C for *Jatropha* to establish. In the dry-hot Panzhihua valley, elevations lower than 1,600 m are suitable silvicultural regions for *Jatropha* (Yang 2006).

There are several silvicultural methods for *Jatropha*: direct seeding and planting nursery raised seedlings and cuttings. In direct seeding, soil moisture needs to be high. The recommended number of seeds is 4–7 per hole, with 3–5 cm soil covering. This method is easy and cheap. However, young seedlings are easily affected by changes in the environment. The pests, diseases, and drought may result in low rate of emergence and uneven seedling growth. The appropriate season for seedling planting is in June or July. Cuttings are planted in February or March before sprouting (Sichuan Forestry Department, Chengdu; personal communication). This method appears to be feasible in high moisture soil, and tends to be expensive on a large scale.

Plantations are often initially stocked with 1,500–1,800 trees per hectare at planting. Pits of size 50 × 50 × 40 cm are prepared for planting the seedlings. Basic fertilization with super phosphate and farmyard manure is recommended during planting. Cultivation and plantation methods used in other parts of the world have been described in Achten et al. (2008).

Jatropha curcas

The research on *Jatropha* has traditionally focussed on its toxic chemical components (Table 3), seed oil (Li et al. 2000; Liao et al. 2003; Liu et al. 2005; She et al. 2005a, She et al. 2005b) and extraction technology (Liu et al. 2005, b; Zeng et al. 2005).

Wei and Liu (2002) studied the pharmacognosy of *Jatropha* as a toxic medicinal plant and described its botanical characters in detail. Song and Chen (2002) analysed the clinical features in patients who accidentally consumed *Jatropha* seeds. The poisoned

patients had multiple dosage-dependent toxic symptoms. Treatment with general antitoxins was suggested as the effective therapy. Huang et al. (1991) isolated three toxic proteins from *Jatropha*, and found their apparent molecular weight to be about 34, 27, and 9.5 kDa, respectively. The first showed the strongest toxicity, with LD₅₀ to mouse at 6.39 mg after celiac injection. Jatropherol (JaI), a diterpene separated from *Jatropha* seed oil, was shown to have no contact but strong stomach toxicity to silkworm (Li et al. 2005). JaI damaged tissue structure of the midgut in silkworm, with damage to the insect digestion system induced by JaI might be an important toxicological mechanism of JaI to silkworm (Table 3).

Zeng et al. (2004) determined the in vitro antibiotic effect of an alcohol extract from *Jatropha* leaf on *Escherichia coli* and *Staphylococcus aureus*. The extract inhibited *E. coli* and *S. aureus*, and the activity against *E. coli* was better than that against *S. aureus*. Li et al. (2004) prepared the poisonous protein, seed oil and its ethanol extract from *Jatropha* seed and studied the insecticidal activity of extracts against *Lipaphis erysimi* (Kaltenbach). The poisonous protein showed no significant effect to *L. erysimi*, while seed oil possessed strong contact toxicity. The contact toxicity of the ethanol extract of seed oil against the aphid was greater than that of the original seed oil. Cheng et al. (2001) compared the molluscicidal efficacy of *Jatropha* seed extract from Yunnan (China) and Mali (Africa) and found that there was no difference between the extracts. The phorbol

Summary of findings in biomedical researches on *Jatropha curcas* in China

Items	Findings	References
<i>Toxicity</i>		
Toxin protein isolation	Three toxin proteins were isolated, their apparent MW were about 34, 27 and 9.5 kDa, respectively	Huang et al. (1991)
Clinical features in patients who accidentally consumed the seeds	The poisoned individuals had multiple toxic symptoms; treatments with general antitoxin and protection to vital organs were effective therapies	Song and Chen (2002)
Toxicity of Jatropherol to 3rd-instar silk worm	The Jatropherol had no contact toxicity but had strong stomach toxicity	Li et al. (2005)
<i>Bacteriostasis and insecticidal activity</i>		
Comparison of molluscicidal efficacy	There were no differences between the extracts from <i>J. curcas</i> plants from Yunnan province and Mali	Cheng et al. (2001)
In vitro antibiotic effect on chicken pathogens	The alcohol extract from <i>Jatropha</i> leaf inhibited chicken <i>Escherichia coli</i> and <i>Staphylococcus aureus</i>	Zeng et al. (2004)
Insecticidal activity of seed extract against <i>Lipaphis erisimi</i>	The poisonous protein showed no significant effect, while the contact toxicity of ethanol extract of seed oil was enhanced	Li et al. (2004)
Antifungal activity of curcumin	Curcumin could inhibit hyphal growth and spore formation	Wei et al. (2004b)
<i>Molecular biological studies</i>		
RAPD analysis	25 µl reaction system (2 mmol l ⁻¹ Mg ²⁺ containing), 150–200 µmol l ⁻¹ dNTPs, 1 U Taq DNA polymerase, 0.4 µmol l ⁻¹ primers, 10–20 ng templates and 44 PCR cycles were the optimal PCR reaction conditions	Sun et al. (2002)
Toxin protein isolation	Curcumin was isolated and purified	Lin et al. (2002)
Curcumin protein cloning	Curcumin protein was cloned and expressed	Lin et al. (2003)
Antitumor effects of curcumin	The obvious antitumor effects of curcumin were reported, and activity related to <i>N</i> -glucosidase activity was suggested as the possible mechanism of action	Lin et al. (2003)
Total RNA extraction	A simple, rapid and highly effective method was introduced	Luo et al. (2005b)
Curcumin protein in kernels	Curcumin was identified by Western-blot	Rong and Wang (2005)

Toxic and antinutrients in *Jatropha curcas* seeds from China (data from our laboratory)

Constituent	Content
Phorbol esters in kernel (mg/g)*	2.2 (0.87–3.32)
Trypsin inhibitor in kernel meal (mg trypsin inhibited/g)	24.5 (18.4–27.5)
Lectin in kernel meal (inverse of the minimum amount of sample in mg/ml of the assay which produced haemagglutination)	102 (51.3–204)
Phytate in kernel meal (% as phytate equivalent)	8.1 (6.2–10.1)

* As phorbol-12-myristate 13-acetate equivalent

Kernel meal, defatted kernel (oil <0.5%). Values in parenthesis are for 18 provenances from different parts of the world (Makkar et al. 1997)

(2002). This study revealed the functional mechanism of curcumin at molecular level for the first time. Lin and Chen (2003) cloned and expressed the protein curcumin from the seeds of *Jatropha*. Lin et al. (2003) determined that curcumin had an antitumor effect and discussed the mechanisms of action related to *N*-glucosidase activity. The presence of curcumin was demonstrated in calli generated from the plants of *Jatropha* (Rong and Wang 2005).

A reliable energy supply and efficient and clean energy utilization are essential for sustainable economic development. China's energy consumption has



doubled in the past ten years (Wu et al. 2006). In 2020, motor vehicles in China will number 130–150 million and the fossil fuel demand by these motor vehicles will be about 256 million tons: about 85 million tons of gasoline and 171 million tons of diesel (Wang 2006). China's share of world CO₂ emission is likely to increase from 12% in 2000 to 18% in 2025, rapidly approaching the USA share of 25% (EIA 2004). Jatropha oil could be used to produce high quality biodiesel (Mandpe et al. 2005). Compared to conventional diesel, biodiesel has the advantage of being a renewable indigenous fuel, the use of which has positive consequences for the environment and rural socio-economy. Jatropha oil can be produced in an environmentally and socially sustainable manner in tropical countries (Francis et al. 2005).

Several parts of the jatropha plant have medical and cosmetic uses. The plant is described as “bitter, damp, cool, toxic, antipruritic and stiptic” (Anonimous 1978). Jatropha is mentioned in the Great Compendium of Chinese Materia Medica (Huang 2001) and the Chinese Dictionary of Medicinal Plants (2003). It is not covered in ancient materia medica and the Chinese Pharmacopoeia (Anonimous 2005). In Yunnan, Panhihua and Hainan, latex of jatropha branches and leaves is used against skin diseases. Jatropha may be consumed by mistake by children, since its seeds are somewhat tasty (Song and Chen 2002), but such accidental consumption is not widely reported. The full potential of jatropha as a medicinal plant has neither been thoroughly researched nor fully realized.

The moisture content of jatropha twigs, trunks, and leaves is relatively high, imparting strong fire tolerance. Jatropha has been planted as a fire barrier since the 1980s. It is also planted as a fire barrier by the natives to prevent the spread of fire outbreaks. The moisture content of aerial parts of jatropha during late drought season was: trunk 60.1%, annual twig 78.3%, tender sprouts 81.4%, and leaves 79.4%. Furthermore, jatropha can be used as a hedge to prevent spread of diseases and insect infestation in afforested areas (Li et al. 2006b).

After oil extraction from seeds, the remaining seed cake is high in protein and other nutrients, and has a

wide variety of applications as an organic fertilizer and soil conditioner. Processing and detoxification can convert the seed cake into high protein animal feed. Under a conservative scenario, 2 million ha of land could be planted with jatropha in China by 2020. These plantations are expected to produce 5.85 million tons of oil per year (Wang 2006) and kernel meal equivalent to 5.6 million tons of soybean meal on protein equivalent basis (45% crude protein). Under an optimistic scenario, the production of oil from jatropha could vary between 70 and 200 million tons per year (Wang 2006). In such a situation detoxified jatropha kernel meal could provide between 67 and 190 million tons of soybean meal on protein equivalent basis. The consumption of animal derived products in China is likely to increase by 41 million tons by 2020. Additional amounts of feed ingredient obtained as a by-product of biodiesel production from jatropha grown largely on barren and wastelands will significantly contribute to achieving the consumption target of biologically high-valued diet.

Jatropha curcas seed cake also has high energy value and can be pressed into briquettes and burned as fuel (Wang 2006). As the seed cake is generated in large quantities after oil extraction, its commercial use is vital for economic viability of the jatropha system. High quality protein concentrate could also be produced from seed cake (Makkar et al. 2008) which after detoxification could also be used in the diets of farm animals and aquaculture species. Seed cake and parts of jatropha plant could also be used for biogas production (Gunaseelan 2009).

Jatropha is a versatile oil plant with many economical and ecological attributes, and has considerable potential in China. The drought resistant plant and can grow on degraded and poor soil, can be used to reclaim eroded land and other poor sites, and has few pests and diseases. Research focused on different ecotypes, improvement of seed quality, plantation techniques, flowering and fruiting characteristics, and harvest and post-harvest handling of seeds is required to help jatropha producers realize its full potential. More research is needed on biomedical aspects of active principles contained in its different parts; botany, agronomy, and ecology of *J. curcas*; and

more information on the actual and potential markets. In the short term, commercial utilization of the seed cake as animal feed in addition to the oil make contribute to increasing the economic viability of jatropha production systems.

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- Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Mu s B (2008) *Jatropha* bio-diesel production and use. *Biomass Bioenerg* 32:1063-1084
- Anon mous (1965) *Jatropha* bio-diesel production and use. *Flora of Hainan*. In: South China Institute of Botany, Chinese Academy of Sciences (eds) *Flora of Hainan* (2). Science Press, Beijing, p 172
- Anon mous (1972) The picture index of senior China plant. In: Institute of Botany, Chinese Academy of Sciences (eds) *The picture index of senior China plant* (2). Science Press, Beijing, p 610
- Anon mous (1978) *The compendium of medical herbs of China*. Editorial Board of the Compendium of Medical Herbs of China (ed) People's Medical Publishing House, Beijing
- Anon mous (1996) *Flora reipublicae popularis sinicae*. In: Editorial board of *Flora reipublicae popularis sinicae* (ed) *Flora Reipublicae Popularis Sinicae*, Science Press, Beijing, vol 44(2), p 148
- Anon mous (1998) *Guangxi Plant Directories*. In: Guangxi Institute of Botany (ed) *Guangxi Plant Directories*, Volume 2 Dicotyledons. Guangxi Institute of Botany, Guangxi, p 226
- Anon mous (2005) *Pharmacopoeia of people's republic of China*. Committee of Chinese Pharmacopoeia, Chemical Industry Press, Beijing
- Chang-wei L, Kun L, You C, Yong-u S (2007) Floral display and breeding system of *Jatropha curcas* L. *For Stud China* 9:114-119
- Chen YS, Zheng S (1987) *Tropical Plants in China*. Beijing, Science Press, p 258
- Chen Y, Wei Q, Tang L, Chen F (2003) Proteins in vegetative organs and seeds of *Jatropha curcas* L and those induced by water and temperature stress. *Chinese J Oil Crop Sci* 25(4):98-103
- Cheng ZY, Huang SX, Zeng QH, Yang Y, Gao ZQ (2001) Comparison of the indoor molluscicidal effects of *Jatropha curcas* L extract from different places. *Chinese J Schisto Cont* 13(4):221-225
- Chinese Dictionary of Herbal Medicine (2003) Jiangsu Xinhua College. Shanghai Science and Technology Press, Shanghai, p 2227
- Deng ZJ, Cheng HY, Song SQ (2005) Studies on *Jatropha curcas* seed. *Acta Botanica Yunnanica* 27(6):605-612
- Dong W (2004) A green energy source for biodiesel production. *Energy Res Inform* 20(2):92-94
- Energy Information Administration (2004) US Department of Energy, Office of integrated analysis and forecasting. US Department of Energy, Washington, DC 20585
- Fei SM, Zhang XD, Yang GY, Zhou JX, Liu FY (2005) On domestic and international situation of energy plant resources and their exploitation. *J Sichuan For Sci Technol* 26(3):20-26
- Francis G, Edinger R, Becker K (2005) A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations. *Nat Resour Forum* 29:12-24
- Goel G, Makkar HPS, Francis G, Becker K (2007) Phorbol esters: structure, biological activity, and toxicity in animals. *Int J Toxicol* 26:279-288
- Gunaseelan VN (2009) Biomass estimates, characteristics, biochemical methane potential, kinetics and energy from *Jatropha curcas* on dry lands. *Biomass Bioenerg* 33:589-596
- Huang TK (2001) *Compendium of Materia Medica*. In: Huang TK (ed) *Compendium of Materia Medica*. Medicine Science and Technology Press, Beijing, p 232
- Huang JJ, Han WD (2006) The current research and perspective utilization on the energy tree species in China. *J Guangdong For Sci Technol* 22(4):106-110
- Huang DR, Huang DH, Guo SX, Pan ZZ, Huang ZQ, Lin JZ (1991) Isolation and properties of curcumin from *Jatropha curcas*. *Prog Biochem Biophys* 18(2):149-151
- Jiang JM, Fei SM, Li H, Lei CH (2004) Comparison of drought-resistance ability of main afforestation species in Panzhihua dry-hot valley. *Transactions of China Pulp and Paper* pp 345-348
- Kun L, Wen-un Y, Li L, Chun-hua Z, Yong-hong C, Yong-u S (2007) Distribution and development strategy for *Jatropha curcas* L. in Yunnan Province, South-west China. *For Stud China* 9:120-126
- Li XY (2005) Cutting technique of *Jatropha curcas*. *Autumn Agri Techn Ser* 7:10-12
- Li WL, Yang H, Lin NY, Xu YL, Xie QL (2000) Study on the chemical constituents of seed oil from *J. curcas*. *J Yunnan Uni* 22(5):324-326
- Li J, Yan F, Wu FH, Yue BS, Chen F (2004) Insecticidal activity of extracts from *Jatropha curcas* seed against *Lipaphis erysimi*. *Acta Phytol Sin* 31(3):289-293
- Li J, Yan F, He WX, Xiao M, Chen YY, Chen F (2005) Toxicity and mechanism of *Jatropha* oil to silk moth, *Bombyx mori*

- the supercritical fluid carbon dioxide extraction technique. *Chem Res Appl* 15(5):704–705
- Lin H (2004) Oil plant—new emerged energy source. *Chin Sci and Technol* 11:50–51
- Lin J, Chen Y (2003) Cloning and expression of curcun, a ribosome-inactivating protein from the seeds of *Jatropha curcas*. *Acta Bot Sin* 45(7):858–863
- Lin J, Yan F, Tang L, Chen F (2002) Isolation, purification and functional investigation on the N-glucosidase activity of curcun from the seeds of *Jatropha curcas*. *High Technol Lett* 11:36–40
- Lin J, Yan F, Tang L, Chen F (2003) Antitumor effects of curcun from *Jatropha curcas* L. *Acta Pharmacol Sin* 24(3):241–246
- Liu DC, She ZH, Liu JB, Ye P, Zhang AQ (2005) Deacidification of *Jatropha curcas* L seed oil with solvent extraction. *China Oil Fat* 30(6):26–28
- Lu WD, Wei Q, Tang L, Yan F, Chen F (2003) Induction of callus from *Jatropha curcas* and rapid propagation. *Chin J Appl Environ Biol* 9(2):127–130
- Luo T, Ma DW, Deng WY, Chen F (2005a) Effect of low temperature on physiological indexes of *Jatropha curcas*. *Chin J Oil Crop Sci* 27(4):50–54
- Luo YY, Wei Q, Zhou LJ, Zhang R, Deng WY, Ren C, Chen F (2005b) A simple, rapid and highly effective method for extracting total RNA from *Jatropha curcas*. *Plant Physiol Commun* 41(3):361–364
- Makkar HPS, Becker K (1999) Nutritional studies on rats and fish (carp *C. prinus carpio*) fed diets containing unheated and heated *Jatropha curcas* meal of a non-toxic provenance. *Plant Foods Human Nutr* 53:182–292
- Makkar HPS, Becker K, Sporer F, Wink M (1997) Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*. *J Agri Food Chem* 45:3152–3157
- Makkar HPS, Aderibigbe AO, Becker K (1998) Comparative evaluation of a non-toxic and toxic variety of *Jatropha curcas* for chemical composition, digestibility, protein degradability and toxic factors. *Food Chem* 62:207–215
- Makkar HPS, Francis G, Becker K (2008) Preparation of protein concentrate from *Jatropha curcas* screw-pressed seed cake and toxic and antinutritional factors in protein concentrate. *J Sci Food and Agric* 88:1542–1548
- Mandpe S, Kadlaskar S, Degen W, Keppeler S (2005) On road testing of Advanced common rail diesel vehicles with biodiesel from the *Jatropha curcas* plants, (Paper no. 2005-26-356). Paper presented at international mobility engineering congress and expo 2005, 23–25 October 2005, Chennai Trade Centre, Nandambakkam, Chennai organised by SAE India
- Min EZ, Tang Z, Du ZX (2005) Perspective of biodiesel industry in China. *Chin Eng Sci* 7(4):1–4
- Rong F, Wang SH (2005) Identification of curcun by western-blot in calli generated from plants of *Jatropha curcas* L. *Chin J Sichuan Uni (Nat Sci Ed)* 42(1):211–214
- She ZH, Liu DC, Liu JB, Ye P, Zhang AQ (2005a) Physicochemical properties and fatty acid composition of *Jatropha curcas* L. seed oil. *China Oil Fat* 30(5):30–31
- She ZH, Liu DC, Tan PY (2005b) Study on methylesterification technology of high acid value *Jatropha curcas* L. seed oil. *China Oil Fat* 30(9):34–36
- Shrivastava S, Banerjee M (2008) In vitro clonal propagation of ph sic nut (*Jatropha curcas* L.): Influence of additives. *Intern J Integr Biol* 3(1):73–79
- Shui J (2005) Excellent gardening plant *Jatropha integrerrima* Jacq. *Pract For Technol* 5:39–40
- Song W, Chen S (2002) Clinical analysis of poisoning with *Jatropha curcas* L. in 86 patients. *Hainan Med* 13(11):3–4
- Su YY, Liu SQ, Zhang WD, Liu WW (2006) Study on preparation of biodiesel with *Jatropha curcas* oil. *Energy Eng* 1:22–266
- Sun Q, Xu Y, Yan F, Chen F (2002) The factors in RAPD analysis of *Jatropha curcas* L. *Chin J Appl Environ Biol* 8(3):259–261
- Tian CL, Guo B, Liu CC (2005) Present situation and prospect of energy plants. *Chin J Biopro Eng* 3(1):14–19
- Wang, G. 2006. Liquid biofuels for transportation, Chinese potential and implications for sustainable agriculture and energy, in the 21st Century: assessment study (<http://.gt.de/de/themen/laendliche-entwicklung/natuerliche-ressourcen/14071.htm>)
- Wang Z-Y, Lin J-M, Xu Z-F (2008) Oil content and fatty acid composition in *Jatropha curcas* seeds collected from different regions. *J South Med Univ* 28:1045–1046
- Wei SJ, Liu SY (2002) The pharmacognosy of venomous medicinal plants. *Guangxi J Trad Chin Med* 25(10):53–54
- Wei Q, Liao Y, Zhou LJ, Zhou JX, Wang SH, Chen F (2004a) Antifungal activity of curcun from seeds of *Jatropha curcas*. *Chin J Oil Crop Sci* 26(3):71–75
- Wei Q, Lu WD, Liao Y, Pan SL, Xu Y, Tang L, Chen F (2004b) Plant regeneration from epicotyl of plant of *Jatropha curcas*. *J Plant Physiol Mol Bio* 30(4):475–478
- Wu SG, Chen P (1988) Feasibility of utilizing *Jatropha curcas* L. seed oil for diesel energy. *Resour Sci* 4:60–65
- Wu GJ, Liu J, Lou ZP, Kang L (2006) Development of energy plant: progress and suggestions. *Bull Chin Acad Sci* 21(1):53–57
- Wu J, Wang SH, Tang L, XU Y, Chen F (2008) Hereditary capacity of seed oil content in *Jatropha curcas* land breeding of variety, CSC High-oil 63. *J Seed Sci* 275:100–104
- Xin YN (2005) Development situation and application foreground of biodiesel fuel. *China Oil* 30(3):49–53
- Yang DS (2006) Ten forestation techniques in Sichuan. Sichuan Science and Technology Press, Chengdu, China
- Zeng LH, Yan F, Chen F (2004) In vitro bacteriostasis of *Jatropha curcas* L. extract against chicken *Escherichia coli* and *Staphylococcus aureus*. *Chin Poult Sci* 8(1):35–37
- Zeng HY, Fang F, Su JL, Li CZ, Jiang LJ (2005) Technique of extracting oils from *Jatropha curcas* seeds. *Jiangsu J Agri Sci* 21(1):69–70
- Zhang SY, Fan WG (2005) Study on photosynthesis of *Jatropha curcas*. *Seeds* 24(8):13–15
- Zhang WD, Song HC, Wei XG, Liu ZM (2001a) Study on growing adaptability of *Jatropha curcas* in Yuanmou county. *Agri Technol* 21(1):21–25

- Zhang WD, Song HC, Wei XG, Liu ZM (2001b) The development of *Jatropha curcas* and protection of environment in Yuanmou county. J Yunnan Normal Univ 21(5):37–42
- Zhang F-L, Niu B, Wang Y-C, Chen F, Wang S-H, Xu Y, Jiang L-D, Gao S, Wu J, Tang L, Jia Y-J (2008) A novel betaine aldehyde dehydrogenase gene from *Jatropha curcas*, encoding an enzyme implicated in adaptation to environmental stress. Plant Sci 174:510–518
- Zheng WJ (1998) Arboretum of China, vol 33. Forestry Press of China, Beijing, pp 2977–2979