Agroforest Syst (2009) 76:487–497
DOI 10.1007/s10457-009-9226-x

Current situation and prospects of *Jatropha curcas* as a multipurpose tree in China

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Received: 27 May 2008 / Accepted: 19 March 2009 / Published online: 5 April 2009

Abstract 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 southwest 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 flowerings 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, flowering 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 Benefits · Biodiesel · Botany · China · Distribution · *Jatropha curcas*

Introduction

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* (Physic nut) 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

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many 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.

Jatropha botany, agronomy, and ecology

Provenances and distribution

Jatropha curcas (Physic 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 mutifida* L., *J. gossypiifolia* L. and *J. integerrima* Jacq. In China *J. curcas* L. has many alternate names, for example Xiaotongzi (Panzhihua), Shuhuasheng (Hainan), Huangzhongshu (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 Panzhihua prefecture in Sichuan, most of Yunnan province and the southwest of Guizhou province. In Sichuan province, jatropha is found in Panzhihua, Yanbian, Miyi, Ningnan, Dechang, Xichang, Huili, and Jinyang Yanyuan counties (Li et al. 2006b). In Yunnan province, jatropha is widely grown in Chuxiong Yi Autonomous City, 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-toxicity 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 twigs. The average toxic protein content of seeds is 4.2%, which was 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 Jishajiang River, and below 1,600 m in branch-valley areas in Huili county of Liangshan state and Yanbian county of Panzhihua 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 was 15.6% more than the parent plant (Huang and Han 2006).

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

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

would be interesting to compare the phorbol ester content in the kernels of seeds from CSC High-toxicity 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 papery leaves. The leaves are 8 to18 cm wide, shiny and glabrous, with exiguous 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 dry. 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 tap root 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 Panzhihua city, the annual height increment of the wild 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. Afterwards 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 wild 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 apomixes but not wind pollination. Jatropha is self compatible, but normally shows outcrossing and requires pollinators. A tendency to promote xenogamy and minimize geitonogamy was 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 Panzhihua 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 9,000–12000 kg per ha (yield from small areas up to one hectare), whereas in large wild 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 were 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 fish fed non-toxic jatropha meal (Makkar and Becker 1999) suggested that the protein quality of jatropha kernel meal is very high.

Table 1 Seed Characters of *Jatropha curcas* from 11 counties in southwest 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)

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

Table 2 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	Cystine	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 μmol m^2 s, respectively. The diurnal variation in the rate of photosynthesis showed a two-peaked curve. Under the dry condition, the light compensation point and the light saturation point of photosynthesis were 193.82 and 697.08 μmol m^2 s, respectively.

Plantation techniques

Seedlings

A germination of 80–90% has been obtained for seeds collected during October to December in Panzhihua. 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 twigs 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 Guizhou. 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 simply 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 were 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).

Biomedical research on toxic components in *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) analyzed the clinical features in patients who accidentally consumed jatropha seeds. The poisoned patients had multiple dosage-dependant toxicity 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. It was suggested that damages to 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 *Staphlococcus 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 esters have strong molluscicical activity (Goel et al. 2007) and the contents of phorbol esters in the jatropha seed samples collected from China and other parts of the world have been of similar order of magnitude (Table 4). Seed of jatropha has a high content of other antinutrients (Makkar et al. 1997) Trypsin inhibitor, lectin, and phytate contents were similar to those from other parts of world (Table 4). Curcin at 5 μg/ml inhibited hyphal growth and spore formation in *Pyriculariaoryzae Cav.* (Wei et al. 2004b).

Luo et al. (2005b) introduced a simple, rapid, and highly effective method for extracting total RNA from jatropha, and a repeatable RAPD analysis was optimised (Sun et al. 2002). Curcin was determined to be a ribosome inactivating protein (RIP) (Lin et al.

Table 3 Summary of findings in biomedical researches on *Jatropha curcas* in China

Items	Findings	References
Toxicity		
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 therapy	Song and Chen (2002)
Toxicity of Jatropherol to 3rd-instar silkworm	The Jatropherol had no contact toxicity but had strong stomach toxicity	Li et al. (2005)
Bacteriostasis and insecticidal activity		
Comparison of molluscicidal efficacy	There were no differences between the extracts from *J. curcas* plants from Yunnan province and Mali	Cheng et al. (2001)
In vitro antibiotic effect on chicken pathogens	The alcohol extract from *Jatropha* leaf inhibited chicken *Escherichia coli* and *Staphlococcus aureus*	Zeng et al. (2004)
Insecticidal activity of seed extract against Lipaphis erysimi	The poisonous protein showed no significant effect, while the contact toxicity of ethanol extract of seed oil was enhanced	Li et al. (2004)
Antifugal activity of curcin	Curcin could inhibit hyphal growth and spore formation	Wei et al. (2004b)
Molecular biological studies		
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	Curcin was isolated and purified	Lin et al. (2002)
Curcin protein cloning	Curcin protein was cloned and expressed	Lin et al. (2003)
Antitumor effects of curcin	The obvious antitumor effects of curcin was reported, and activity related to *N*-glycosidase 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)
Curcin protein in kernels	Curcin was identified by Western-blot	Rong and Wang (2005)

Table 4 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 haem-agglutination)	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 world (Makkar et al. 1997)

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

As a renewable energy source

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 twenty 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 only 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 CO_2 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).

Other uses

Several parts of the jatropha plant have medical and cosmetic uses. The plant is described as "bitter, damp, cool, toxic, antipruritic and styptic" (Anonymous 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 (Anonymous 2005). In Yunnan, Panzhihua 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 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 fertiliser 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).

Conclusions

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 biomedicinal 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 may contribute to increasing the economic viability of jatropha production system.

Acknowledgments This review paper was prepared under the common efforts of Sino–German Scientists collaborating in the BMBF-MoST joint project. Thanks are to Drs. Jianxin Liu, Qiyu Diao, Weiyun Zhu and Klaus Becker for critically reviewing the manuscript.

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