industrial crops and products xxx (2008) xxx–xxx

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Review

An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): A review

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ARTICLE INFO

Article history:
Received 12 September 2006
Received in revised form
1 January 2008
Accepted 2 January 2008

Keywords:
Jatropha curcas
Biofertilizers
Curcin
RIP gene
Phorbol esters
Biodiesel

ABSTRACT

Jatropha curcas, a multipurpose, drought resistant, perennial plant belonging to Euphorbiaceae family is gaining lot of importance for the production of biodiesel. It is a tropical plant that can be grown in low to high rainfall areas either in the farms as a commercial crop or on the boundaries as a hedge to protect fields from grazing animals and to prevent erosion. Before exploiting any plant for industrial application, it is imperative to have complete information about its biology, chemistry, and all other applications so that the potential of plant could be utilized maximally. The taxonomy, botanical description of the plant, its distribution and ecological requirement are discussed in this paper. Various propagation methods including tissue culture to get large diseased resistant plantlets of *Jatropha* are reviewed. The detailed information about the presence of various chemicals including toxins in different parts of the plant is summarized. The possibilities on the exploitation of potential of plant for various applications have been explored. The information about the toxins and detoxification methods is collected and discussed. Overall, this paper gives an overview on covering the biology, chemistry, toxicity of seeds and detoxification and various industrial uses, emphasizing the benefits on the rural and urban economy.

Contents

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0926-6690/$ – see front matter
doi:10.1016/j.indcrop.2008.01.001

1. Introduction

The use of biomass to provide energy has been fundamental to the development of civilization. Biomass contributes a significant share of global primary energy consumption and its importance is likely to increase in future world energy scenarios (Vasudevan et al., 2005). Improved agronomic practices of well-managed biomass plantations will also provide a basis for environmental improvement by helping to stabilize certain soils, avoiding desertification, which is already occurring rapidly in tropical countries. *Jatropha* is a multipurpose species with many attributes and considerable potential. Nearly 40% of the land area in India is wasteland. Importance is given on the plantation of *Jatropha* species on wastelands, for the protection of the environment and fulfilling future energy requirements.

The wood and fruit of *Jatropha* can be used for numerous purposes including fuel. The seeds of *Jatropha* contain viscous oil, which can be used for manufacture of candles and soap, in cosmetics industry, as a diesel/paraffin substitute or extender. This latter use has important implications for meeting the demand for rural energy services and also exploring practical substitutes for fossil fuels to counter greenhouse gas accumulation in the atmosphere. These characteristics along with its versatility make it of vital importance to developing countries (Foidl and Kashyap, 1999).

Jatropha, a drought-resistant shrub or tree, which is widely distributed in the wild or semi-cultivated areas in Central and South America, Africa, India and South East Asia (Cano-Asseleih, 1986; Cano-Asseleih et al., 1989). The first commercial applications of *Jatropha* were reported from Lisbon, where the oil imported from Cape Verde was used for soap production and for lamps. In addition to being a source of oil, *Jatropha* also provides a meal that serves as a highly nutritious and economic protein supplement in animal feed, if the toxins are removed (Becker and Makkar, 1998). The plant can be used to prevent soil erosion, to reclaim land, grown as a live fence, especially to exclude farm animals and also planted as a commercial crop (Heller, 1996). Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has a honey production potential. Its wood and fruit can be used for numerous purposes including fuel. It is easy to establish and grows relatively quickly. The purpose of this review is to provide information about its potential and current development in the field of *Jatropha* research.

2. Biological and chemical aspects

2.1. Taxonomy and botanical description

The genus *Jatropha* belongs to tribe Joannesieae in the Euphorbiaceae family and contains approximately 170 known species. Linnaeus (1753) was the first to name the physic nut *Jatropha* L. in "Species Plantarum" and this is still valid today. The genus name *Jatropha* derives from the Greek word *jatrós* (doctor) and *trophé* (food), which implies medicinal uses. The physic nut, by definition, is a small tree or large shrub, which can reach a height of three to five meters, but under favorable conditions it can attain a height of 8 or 10 m. The plant shows articulated growth, with a morphological discontinuity at each increment. The branches contain latex. Normally, five roots are formed from seedlings, one central and four peripheral. A tap root is not usually formed by vegetatively propagated plants. Leaves five to seven lobed, hypostomatic and stomata are of paracytic (Rubiaceous) type.

The trees are deciduous, shedding the leaves in dry season. Flowering occurs during the wet season and two flowering peaks are often seen, i.e. during summer and autumn. In permanently humid regions, flowering occurs throughout the year. The inflorescence is axillary paniculate polychasial cymes. The plant is monoecious and flowers are unisexual; occasionally hermaphrodite flowers occur (Dehgan and Webster, 1979). A flower is formed terminally, individually, with female flowers (tricarpellary, syncarpous with trilocular ovary) usually slightly larger and occurs in the hot seasons. In conditions where continuous growth occurs, an unbalance of pistillate or staminate flower production results in a higher number of female flowers. Ten stamens are arranged in two distinct whorls of five each in a single column in the androecium, and in close proximity to each other. In the gynoecium, the three slender styles are connate to about two-thirds of their length, dilating to massive bifurcate stigma (Dehgan and Webster, 1979). The rare hermaphrodite flowers can be self-pollinating. The flowers are pollinated by insects especially honey bees. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits. With good rainfall conditions nursery plants may bear fruits after the first rainy season, and directly sown plants after the second rainy season. Three, bivalved cocci is formed after the seeds mature and the fleshy exocarp dries. The seeds mature about 3–4 months after flowering. The seeds are black and the seed weight per 1000 is about 727 g, there are 1375 seeds/kg in the average. Singh

(1970) described the microscopical anatomy of fruits. Gupta (1985) investigated the anatomy of other plant parts. The physic nut is a diploid species with $2n = 22$ chromosomes.

2.2. Distribution and ecological requirement

Jatropha was probably distributed by Portuguese seafarers via the Cape Verde Islands and Guinea Bissau to other countries in Africa and Asia (Heller, 1996). It is assumes that the Portuguese brought the physic nut to Asia. It is well adapted to arid and semi-arid conditions. *Jatropha* grows almost anywhere except waterlogged lands, even on gravelly, sandy and saline soils. It can thrive on the poorest stony soil. It can grow even in the crevices of rocks. The leaves shed during the winter months form mulch around the base of the plant. The organic matter from shed leaves enhances earthworm activity in the soil around the root-zone of the plants, which improves the fertility of the soil. Regarding climate, *Jatropha* is found in the tropics and subtropics and likes heat, although it does well even in lower temperatures and can withstand a light frost. It will grow under a wide range of rainfall regimes from 250 to over 1200 mm per annum (Katwal and Soni, 2003). In low rainfall areas and in prolonged rainless periods, the plant sheds its leaves as a counter to drought. Its water requirement is extremely low and it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss. *Jatropha* is also suitable for preventing soil erosion and shifting of sand dunes. It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content (Openshaw, 2000). On heavy soils, root formation is reduced. *Jatropha* is a highly adaptable species, but its strength as a crop comes from its ability to grow on very poor and dry sites.

2.3. Propagation methods and crop improvement

Jatropha grows readily from seeds or cuttings; however, trees propagated by cuttings show a lower longevity and possess a lower drought and disease resistance than those propagated by seeds (Heller, 1996), this might have been due to trees produced from cuttings do not produce true taproots (hence less drought tolerant), rather they produce pseudo-taproots that may penetrate only 1/2 to 2/3rd the depth of the soil as taproots produced on trees grown seed.

There are various methods to cultivate *Jatropha*, which vary from region to region and also on climatic conditions. These are: direct seeding, pre-cultivation of seedlings (nursery raising), transplanting of spontaneous wild plants and direct planting of cuttings. Wider spacing (3 m × 3 m) is reported to give larger yields of fruit, at least in early years (Heller, 1996). In different countries and regions the seed yields of *Jatropha* may range from 0.1 to 15 tonnes/ha/year (Ouwens et al., 2007). Kobilke (1989) in Cape Verde, conducted comparative research on the influence of different propagation methods on survival and vegetative development. In better rainfall or good moisture condition the plantation could also be established by direct seeding. The survival rate depended not only on sowing time and depth of sowing, but also on the trial year. When establishing a physic nut crop, the survival rate can be influenced by the choice of cultivation method. Two factors are generally responsible for sprouting: the age of the plant from which cuttings are taken and the position of the cutting within the plant, it might have been due to declines of rooting ability of many woody plants with age, when the source is a seedling derived mother plant. Distal portion of the stock plants are first to exhibit this reduced rooting potential, while cuttings from the lower or juvenile regions of the plants generally maintain a higher rooting capacity than those from the upper regions (Hartmann and Kester, 1983). The application of biofertilizers containing beneficial microbes showed a promoting effect on the growth of *Jatropha*. In most of the cases the biomass yield were found to be slightly higher with vermi-compost than farmyard manure but the reverse was observed in some cases wherein improvement of stem length was noticed with farmyard manure (Kumar and Sharma, 2005). The seed yield per plant could be enhanced by employing biotechnological tools like marker-assisted selection of quality planting material, discussed later in this section.

Tissue cultures have been developed for the propagation and storage of selected genotypes of tropical plants (Engelmann, 1991). These techniques provide higher multiplication rate then the conventional breeding procedure and also minimized the risk of infections by microbes and insect pests, reduced genetic erosion, space requirements and expenses in labor costs. Promising results from aseptic culture of various genotypes of *Jatropha* from both India and Nicaragua were obtained, which formed a base for future genetic improvement of this species (Sujatha and Dingra, 1993; Sujatha and Mukta, 1996; Machado et al., 1997; Sujatha and Prabakaran, 2003; Wei et al., 2004). Genetic variation in seed morphology and oil content of *Jatropha* is of great potential in tree improvement programs, unfortunately no much work has been done on germplasm conservation. However, Ginwal et al. (2005) reported seed source variability in central India, and Kaushik et al. (2007) studied the variation in seed trait and oil content in 24 accessions collected from Haryana state, India. Use of molecular markers are of great significance in applying genetic technologies to crop improvement such as DNA fingerprinting of plant germplasm, introduction of new strain, marker assisted selection and targeted map based cloning etc. The first advancement came with the introduction of RFLP markers. It helps in assessing the molecular diversity of *Jatropha* germplasm and can be used in breeding program (Mohan et al., 1997; Kumar, 1999). Recently a new full length cDNA of stearoyl-acyl carrier protein desaturase was obtained by RT-PCR and RACE techniques from developing seeds of *Jatropha* and the gene was functionally expressed in *E. coli* (Tong et al., 2006). It is an important enzyme for fatty acid biosynthesis in higher plants and also plays an important role in determining the ratio of saturated fatty acid to unsaturated fatty acids in plants (Lindqvist et al., 1996). For understanding the molecular mechanism of salt and drought tolerance, a new full length cDNA encoding aquaporin (JcPIP2) was isolated from seedling of *Jatropha curcas*, the abundance of JcPIP2 was induced by heavy drought stress and it play an important roles in rapid growth of *Jatropha* under dry conditions (Ying et al., 2007).

2.4. Chemical composition of its various parts

The chemicals isolated from different parts of the plant are shown in the Table 1. These chemicals can be used in var-

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Table 1 – Chemicals isolated from different parts of the plant

Various parts	Chemical composition	References
Aerial parts	Organic acids (*o* and *p*-coumaric acid, *p*-OH-benzoic acid, protocatechuic acid, resorsilic acid, saponins and tannins	Hemalatha and Radhakrishnaiah (1993)
Stembark	β-Amyrin, β-sitosterol and taraxerol	Mitra et al. (1970)
Leaves	Cyclic triterpenes stigmasterol, stigmast-5-en-3β, 7 β-diol, stigmast-5-en-3β,7α-diol, cholest-5-en-3β,7β-diol, cholest-5-en-3fl,7α-diol, campesterol, β-sitosterol, 7-keto-β-sitosterol as well as the β-D-glucoside of β-sitosterol. Flavonoids apigenin, vitexin, isovitexin	Mitra et al. (1970), Khafagy et al. (1977), Hufford and Oguntimein (1987)
	Leaves also contain the dimer of a triterpene alcohol ($C_{63}H_{117}O_9$) and two flavonoidal glycosides	Khafagy et al. (1977)
Latex	Curcacycline A, a cyclic octapeptide	Van den Berg et al. (1995)
	Curcain (a protease)	Nath and Dutta (1991)
Seeds	Curcin, a lectin	Stirpe et al. (1976)
	Phorbolesters	Adolf et al. (1984), Makkar et al. (1997)
	Esterases (JEA) and Lipase (JEB)	Staubmann et al. (1999)
Kernal and press cake	Phytates, saponins and a trypsine inhibitor	Aregheore et al. (1997), Makkar and Becker (1997), Wink et al. (1997)
Roots	β-Sitosterol and its β-D-glucoside, marmesin, propacin, the curculathyranes A and B and the curcusones A–D. diterpenoids jatrophol and jatropholone A and B, the coumarin tomentin, the coumarino-lignan jatrophin as well as taraxerol	Naengchomnong et al. (1986, 1994)

ious industrial applications. Depending on the variety, the decorticated seeds contain 40–60% of oil (Liberalino et al., 1988; Gandhi et al., 1995; Sharma et al., 1997; Wink et al., 1997; Makkar et al., 1997; Openshaw, 2000), which is used for many purposes such as lighting, as a lubricant, for making soap (Rivera-Lorca and Ku-Vera, 1997) and most importantly as biodiesel.

Jatropha oil contains approximately 24.60% of crude protein, 47.25% of crude fat, and 5.54% of moisture contents (Akintayo, 2004). Numerous sources are available on the fatty acid composition of physic nut oil originating from different countries. The oil fraction of *Jatropha* contains saturated fatty acids mainly palmitic acid (16:0) with 14.1% and stearic acid (18:0) with 6.7%. Unsaturated fatty acids consisted of oleic acid (18:1) with 47.0%, and linoleic acid (18:2) with 31.6%. The oil with high percentage of monounsaturated oleic and polyunsaturated linoleic acid has a semi-drying property (partially hardens when the oil is exposed to air). This semi-drying oil could be an efficient substitute for diesel fuel. Treatment of plants with growth regulators significantly influenced the production of hydrocarbons. Among the treatments, ethephon and morphactin induced the maximum production of hydrocarbon with 5.0 and 5.4%, respectively (Augustus et al., 2002).

2.5. *Seed and its toxicity*

The seeds of physic nut are a good source of oil, which can be used as a diesel substitute. However, the seeds of *J. curcas* are, in general, toxic to humans and animals. Curcin, a toxic protein isolated from the seeds, was found to inhibit protein synthesis in *in vitro* studies. The high concentration of phorbol esters present in *Jatropha* seed has been identified as the main toxic agent responsible for *Jatropha* toxicity (Adolf et al., 1984; Makkar et al., 1997). These phorbol esters are found in plants belonging to the families Euphorbiaceae and Thymelaeaceae (Ito et al., 1983). Several cases of *J. curcas* nut poisoning in humans after accidental consumption of the seeds have been reported with symptoms of giddiness, vomiting and diarrhoea and in the extreme condition even death has been recorded (Becker and Makkar, 1998). Ionizing radiation treatment could serve as a possible additional processing method for inactivation or removal of certain antinutritional factors such as phorbol esters, phytates, saponins and lectins (Siddhuraju et al., 2002). It is not possible to destroy phorbol esters by heat treatment because they are heat stable and can withstand roasting temperature as high as 160 °C for 30 min. However, it is possible to reduce its concentration in the meal by chemical treatments. This treatment is promising, but in economic terms it is expensive to produce *Jatropha* meal from it (Aregheore et al., 2003). Martínez-Herrera et al. (2006) studied the nutritional quality and the effect of various treatments (hydrothermal processing techniques, solvent extraction, solvent extraction plus treatment with $NaHCO_3$ and ionizing radiation) to inactivate the antinutritional factors in defatted *Jatropha* kernel meal of both toxic and non-toxic varieties from different regions of Mexico. Complete removal of the toxins is therefore necessary before *Jatropha* oil can be used in industrial applications or in human medicine, the oil must be shown to be completely innocuous before it is used commercially.

3. Uses of *Jatropha* products

3.1. *As hedge*

Jatropha is an excellent hedging plant generally grown in most part of India as live fence for protection of agricultural fields against damage by livestock as unpalatable to cattle and goats. Thus in addition to seed yields it serves the purpose of bio

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Table 2 – Nutritional analysis of oil seed cakes, and manure (%) (Delgado and Parado, 1989)

Property	*J. curcas* oil cake	Neem oilcake	Cow manure
Nitrogen	3.2–4.44	5.0	0.97
Phosphorus	1.4–2.09	1.0	0.69
Potassium	1.2–1.68	1.5	1.66

fence with respect to cost effectiveness as compared to wire fence.

3.2. *As green manure and fertilizers*

Seed cake or press cake is a by-product of oil extraction. *Jatropha* seed cake contains curcin, a highly toxic protein similar to ricin in castor, making it unsuitable for animal feed. However, it does have potential as a fertilizer or biogas production (Staubmann et al., 1997; Gubitz et al., 1999), if available in large quantities; it can also be used as a fuel for steam turbines to generate electricity. The defatted meal has been found to contain a high amount of protein in the range of 50–62%, and the level of essential amino acids except lysine is higher than the FAO reference protein (Makkar et al., 1998).

Being rich in nitrogen, the seed cake is an excellent source of plant nutrients. In a green manure trial with rice in Nepal, the application of 10 tonnes of fresh physic nut biomass resulted in increase yield of many crops (Sherchan et al., 1989). Another use of *Jatropha* seed cake is as a straight fertilizer, its properties were compared with those of other organic fertilizers with regard to nitrogen, phosphorus and potassium content which is shown in the Table 2.

In preliminary experiment, *Jatropha* seed cake is utilized as feedstock for biogas production (Karve, 2005; Visser and Adriaans, 2007). Experiments on use of biogas slurry as a fertilizer are still in the early stages. Recently experimentation on solid-state fermentation of *Jatropha* seed cake showed that, it could be a good source of low cost production of industrial enzymes (Mahanta et al., 2008).

3.3. *As food*

The physic nut seed is eaten in certain regions of Mexico once it has been boiled and roasted (Delgado and Parado, 1989). *Jatropha* can be toxic when consumed, however, a non-toxic variety of *Jatropha* is reported to exist in some provenances of Mexico and Central America, said not to contain toxic Phorbol esters (Makkar et al., 1998). This variety is used for human consumption after roasting the seeds/nuts, and "the young leaves may be safely eaten, steamed or stewed" (Duke, 1985a; Ochse, 1931) Sujatha et al. (2005) have been established the protocols for *in vitro* propagation of non-toxic variety of *Jatropha* through axillary bud proliferation and direct adventitious shoot bud regeneration from leaf segments.

3.4. *Soap*

The glycerin that is a by-product of biodiesel can be used to make soap, and soap can be produced from *Jatropha* oil itself. In either case the process produces a soft, durable soap and is a simple one, well adapted to household or small-scale industrial activity.

3.5. *Pesticide*

The oil and aqueous extract from oil has potential as an insecticide. For instance it has been used in the control of insect pests of cotton including cotton bollworm and on pests of pulses, potato and corn (Kaushik and Kumar, 2004). Methanol extracts of *Jatropha* seed (which contains biodegradable toxins) are being tested in Germany for control of bilharzia-carrying water snails.

3.6. *Charcoal*

In simple charcoal making, 70–80% of wood energy is lost with yield of only 30% in an industrial process, where charcoal is still one of the few simple fuel options. *Jatropha* wood is a very light wood and is not popular as a fuel wood source because it burns too rapidly. The use of press cake as a fertilizer is more valuable to increase crop production then charcoal making from it (Benge, 2006). However, the extraction of oil from *Jatropha* seeds is of much higher economic value than converting the wood to charcoal. Converting *Jatropha* seed shells into charcoal would be economically feasible, only if we have a large source of seed shells from *Jatropha* plantations. The scientist concluded that *Jatropha* wood would not be of much value for either charcoal or firewood (Benge, 2006).

3.7. *Medicinal uses*

All parts of *Jatropha* (seeds, leaves and bark) have been used in traditional medicine and for veterinary purposes for a long time (Dalziel, 1955; Duke, 1985b; Duke, 1988). Uses of various parts of *Jatropha* in the treatment of disease have been presented in Table 3. Some compounds (Curcacycline A) with antitumor activities were reportedly found in this plant (Van den Berg et al., 1995). Substances such as phorbol esters, which are toxic to animals and humans, have been isolated and their molluscicidal, insecticidal and fungicidal properties have been demonstrated in lab-scale experiments and field trials (Nwosu and Okafor, 1995; Solsoloy and Solsoloy, 1997).

The seed oil can be applied to treat eczema and skin diseases and to soothe rheumatic pain (Heller, 1996). The 36%

Table 3 – Uses of different parts of *J. curcas* in medicines (Heller, 1996; Kaushik and Kumar, 2004)

Plant part used	Diseases
Seeds	To treat arthritis, gout and jaundice
Tender twig/stem	Toothache, gum inflammation, gum bleeding, pyorrhoea
Plant sap	Dermatomucosal diseases
Plant extract	Allergies, burns, cuts and wounds, inflammation, leprosy, leucoderma, scabies and small pox
Water extract of branches	HIV, tumor
Plant extract	Wound healing

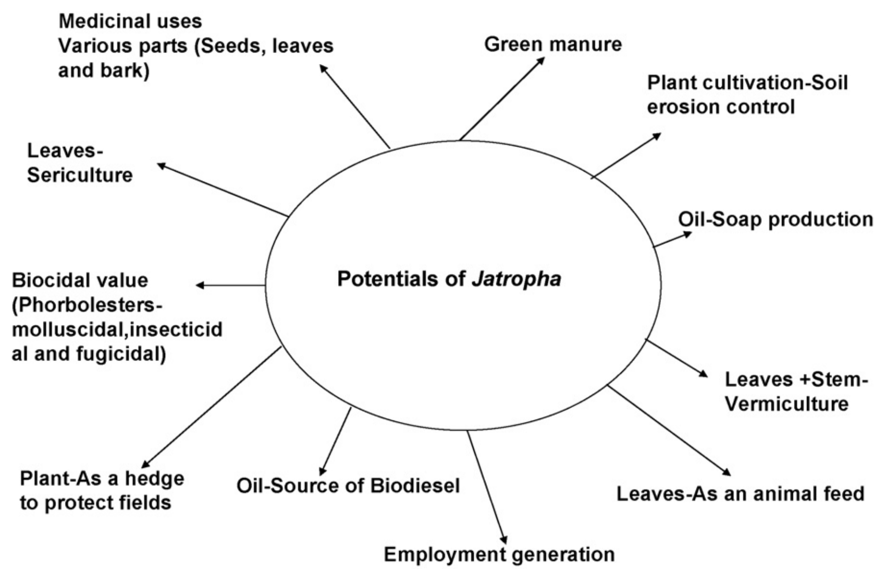

Fig. 1 – Economic significance of *J. curcas*.

linoleic acid (C18:2) content in *Jatropha* kernel oil is of possible interest for skincare. Furthermore, Goonasekera et al. (1995) showed that various solvent extracts of *Jatropha* have an abortive effect. The oil has a strong purgative action and is also widely used for skin diseases and to soothe pain such as that caused by rheumatism. The oil is used as a cathartic purgative (Jamalgota) and for the treatment of skin ailments (Duke, 1988). The latex itself has been found to be strong inhibitors to watermelon mosaic virus (Tewari and Shukla, 1982). The leaves and latex are used in healing of wounds, refractory ulcers, and septic gums and as a styptic in cuts and bruises. A proteolytic enzyme (curcain) has been reported to have wound healing activity in mice (Nath and Dutta, 1997; Villegas et al., 1997). Investigation of the coagulant activity of the latex of *Jatropha* showed that whole latex significantly reduced the clotting time of human blood. Diluted latex, however, prolonged the clotting time, at high dilutions, the blood did not clot at all (Osoniyi and Onajobi, 2003). Topical application of *Jatropha* root powder in paste form is common ethnobotanical practices for the treatment of inflammation, which has been followed by Bhil tribes from Rajasthan area in India and it was confirmed in albino mice and the successive solvent extraction of these roots was carried out by ether and methanol. The methanol extract of these roots exhibited systemic and significant anti-inflammatory activity in acute carrageenan-induced rat paw edema (Mujumdar and Misar, 2004). Economic significance of Jatropha are presented in Fig. 1.

3.8. *As an energy source*

The oil from *Jatropha* is regarded as a potential fuel substitute. The types of fuels, which can be obtained directly from the *Jatropha* plant, are; wood, the whole fruit and parts of the

Table 4 – Fatty acid composition, saponification number (SN), iodine value (IV) and cetane number (CN) of fatty acid methyl ester of some selected seed oils (Bringi, 1987; Singh and Singh, 1991; Tyagi and Kakkar, 1991)

Sr. no.	Sources	Oil[a]	CN	MP[b]	SN	IV	Fatty acid composition (%)[c]
1.	*Jatropha curcas* Linn.	40.0	52.31	–	202.6	93.0	14:0(1.4), 16:0(15.6), 18:0(9.7), 18:1(40.8), 18:2(32.1), 20:0(0.4)
2.	*Pongamia pinnata* Pierre	33.0[e]	55.84	–	196.7	80.9	16:0(10.6), 18:0(6.8), 18:1(49.4), 18:2(19.0), 20:0(4.1), 20:1(2.4), 22:0(5.3), 24:0(2.4)
3.	*Madhuca indica* JF Gmel	40.0[e]	56.61	–	202.1	74.2	14:0(1.0), 16:0(17.8), 18:0(14.0), 18:1(46.3), 18:2(17.9), 20:0(3.0)
4.	*Euphorbia helioscopia* Linn.	31.5[e]	34.25	–	206.7	170.9	12:0(2.8), 14:0(5.5), 16:0(9.9), 18:0(1.1), 18:1(15.8), 18:2(22.1), 18:3(42.7)
5.	*Mesua ferrea* Linn.	68.5[d]	55.10	–	201.0	81.3	14:0(0.9), 16:0(10.8), 18:0(12.4), 18:1(60.0), 18:2(15.0), 20:0(0.9)

[a] Percent oil content expressed in w/w.
[b] Melting point/freezing point of oils and (–) indicates the liquid state of oil at room temperature.
[c] osa: other saturated acid.
[d] Oil from kernel.
[e] Oil from seed.

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Table 5 – Properties of diesel, methanol, *Jatropha* oil and methyl ester of *Jatropha* oil (Vinayak and Kanwarjit, 1991; Basker, 1993)

Properties	Diesel	*Jatropha* oil	Methyl ester of *Jatropha* oil	Methanol
Density (kg m^{-3})	840	918.6	880	790
Calorfic value (kJ kg^{-1})	42,490	39,774	38,450	19,674
Viscosity (cst)	4.59	49.93	5.65	–
Cetane number	45–55	40–45	50	3–5
Flash point (°C)	50	240	170	–
Carbon residue (%)	0.1	64	0.5	0.0

fruit which can be burnt separately or in combination. Processing increases the energy value of the product, but the overall energy availability decreases unless a use can be found for the by-products. Recently novel approach is developed for extraction of oil from seed kernel of *Jatropha* by using enzyme assisted three-phase partitioning (Shah et al., 2004).

3.9. *Biodiesel from physic nut*

Biodiesel is made from virgin or used vegetable oils (both edible and non-edible) and animal fats through trans-esterification and is a diesel substitute and requires very little or no engine modifications up to 20% blend and minor modification for higher percentage blends. *Jatropha* oil can be used as fuel in diesel engines directly and by blending it with methanol (Gubitz et al., 1999). The seed oil of *Jatropha* was used as a diesel fuel substitute during the World War II. Engine tests with *Jatropha* oil were done in Thailand, showing satisfactory engine performance (Takeda, 1982). For African countries, the feasibility of the production of fatty acid ethyl esters from *Jatropha* oil was studied (Eisa, 1997). The economic evaluation has shown that the biodiesel production from *Jatropha* is very profitable provided the by-products of the biodiesel production can be sold as valuable products (Foidl and Eder, 1997). Berchmans and Hirata (2008) and Tiwari et al. (2007) have been developed a technique to produce biodiesel from *Jatropha* with high free fatty acids contents (15% FFA), in which two-stage trans-esterification process was selected to improve methyl ester yield. The first stage involved the acid pretreatment process to reduce the FFA level of crude *Jatropha* seed oil to less than 1% and second was the alkali base catalyzed trans-esterification process gave 90% methyl ester yield. In order to reduce the cost of biodiesel fuel production from *Jatropha*, the lipase producing whole cells of *Rhizopus oryzae* immobilized onto biomass support particles was used and found to be a promising biocatalyst for producing biodiesel (Tamalampudi et al., 2007). Moreover important properties of *Jatropha* and other selected seed oil are presented in Table 4. More efficient expeller system can be used to extract a higher % of oil from the seeds, which in turn should produce higher profits in a *Jatropha* system, since oil sells for more than the residual seed cake.

The simple technology specially developed for this chemical process can also be performed in less industrialized countries (Mittelbach et al., 1983; Connemann, 1994). Use of methyl ester of *Jatropha* oil and dual fuel operation with methanol induction can give better performance and reduced smoke emissions than the blend. Dual fuel operation showed the lowest smoke and NO levels (Senthil et al., 2003). The properties of diesel, *Jatropha* oil, methanol and methyl ester of *Jatropha* oil are summarized in Table 5. Sarin et al. (2007) have been examined the blends of *Jatropha* and Palm biodiesel for their physico-chemical properties and to get optimum mix of them to achieve better low temperature and improved oxidation stability needed for South Asian and South East-Asian countries.

3.10. *Non-energy source*

It is a woody plant and, therefore, its various parts can be used for a number of purposes, especially as fuel, sticks and poles. In some countries, the live pole is used to support vines such as the vanillin plant. Bees pollinate their flowers, thus it is possible to have apiaries in association with *Jatropha* areas. A varnish can be made from the oil and the leaves could be feedstock for silk worms but not everywhere. For example, the experiments conducted by the authors, on rearing of *Philosamia ricini* on *Jatropha* leaves, concluded 100% mortality of erisilk worm *P. ricini* on leaf biomass.

4. Potential conservation benefits

The primary conservation benefits to be derived from production of *Jatropha* relate to improved soil restoration and management. The findings of Kumar et al. (2008), have shown that the heavy metal contaminated soil can be restored by using combination of industrial wastes and suitable bioinoculants strain (*Azotobacter*). *Jatropha* in addition to protecting crops from livestock, it reduces wind erosion and pressure on timber resources and increases soil moisture retention. Nevertheless, *Jatropha* does mine soil nutrients. *Jatropha* oil projects are expected to provide income and organic fertilizer to increase crop yields, as well as being an ecologically friendly source of alternative energy to rural farmers.

5. Conclusions

The *Jatropha* industry is at a very early stage of development, though there are vigorous efforts to promote it, if successful, will alter the picture considerably. There are areas in the world where interest in the plant is especially strong, such as Central America where it was originated, and Mali, where it is widely grown as a live hedge and a lot of research has been done on biodiesel derived from it. *Jatropha* is one among many oil seeds that can be used to produce biodiesel, soap and fertilizer. The economics of the industry depends significantly on production yields. A key determinant is the costs of soap production and efficiency with which oil is extracted from the

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seeds for biodiesel production. Knowledge of physical properties and their dependence on moisture content of *Jatropha* seed is essential to improve the design of equipment for harvesting, processing and storage of seeds. Limited research has been conducted on physical properties of *Jatropha* seeds, however some researchers found out some physical and mechanical properties of *Jatropha* at particular moisture content (Mangaraj and Singh, 2006; Sirisomboon et al., 2007; Garnayak et al., 2008).

Currently, growers are unable to achieve the optimum economic benefits from the plant, especially for its various uses. The markets of different products from this plant have not been properly explored or quantified. Consequently, the actual or potential growers including those in the subsistence sector do not have an adequate information base about the potential and economics of this plant to exploit it commercially.

It is, therefore, timely to examine the potential role that *Jatropha* can play in meeting some of the needs for energy services for rural communities and also creating avenues for greater employment. In India private sector has a long history of exploiting oilseeds and has developed the infrastructure necessary to gain profit from this industry. Costly machinery, such as expellers, is amortized rather quickly since the industry is not based on any one oil seed crop, rather is not based on a number of different oil seeds that are processed year around, and the machinery is run constantly. Furthermore, the government now provides a guaranteed market and price since it has dictated that fuels must contain 10% biodiesel oil. Therefore, supply and demand for biodiesel in India is much different than in other countries and projected to create entirely new production systems. In Indian context, development of biodiesel would not only serve to reduce import of petrodiesel but also in generation of employment opportunities, accelerated rural development and meeting the environmental obligations such as reduction of green house gases (India can tap the US$ 53-billion global market for carbon trading by promoting biofuels uses and production), carbon sequestration, etc. Further large wasteland could be utilized for the cultivation of non-edible oil producing trees for production of biodiesel.

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Please cite this article in press as: Kumar, A., Sharma, S., An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): A review, Ind. Crops Prod. (2008), doi:10.1016/j.indcrop.2008.01.001

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Please cite this article in press as: Kumar, A., Sharma, S., An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): A review, Ind. Crops Prod. (2008), doi:10.1016/j.indcrop.2008.01.001