Chapter 15
Assessment of the Potential of *Jatropha curcas* for Energy Production and Other Uses

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Introduction

Present environmental concerns with climate change led scientists to explore plant based fuels such as biodiesel, because it is renewable, non-toxic, biodegradable and environmentally friendly. In comparison to petroleum diesel, biodiesel decreases the emission of CO_2, sulphur, hydrocarbon, particle matter and smoke during the combustion process (Shu et al. 2007). Furthermore, burning of biodiesel has no net addition to atmospheric CO_2 levels, because it is made from materials produced via photosynthetic carbon fixation. From the economic view point, biodiesel can be produced at low cost on a commercial scale from agricultural and agroforestry crops (Wood 2005). Biodiesel is monoalkyl esters of fatty acids derived from vegetable oils and animal fats that is known as clean and renewable fuel. Biodiesel is usually produced by transesterification of vegetable oils or animal fats with methanol or ethanol (Knothe 2006). The concept of using biofuel in diesel engines has originated more than 100 years ago when Rudolf Diesel tested vegetable oil (i.e., peanut oil) as fuel in his engine. However due to abundant supply of petro-diesel, research and development on vegetable oil were not seriously pursued. It received attention only recently when it was realized that petroleum fuels are dwindling fast and environment friendly renewable substitutes are to be identified (Agarwal and Das 2000). For this purpose many researchers exploited several commercially edible oils as feedstocks for biodiesel. Fortunately, nonedible vegetable oils, mostly produced by oilseed trees and shrubs can provide an alternative to edible oils for production of biodiesel not competing with food resources. The need of nonedible vegetable oils drawn the attention on *Jatropha curcas* (hereafter referred to as Jatropha), which grows in tropical and sub tropical climates across the developing world (Openshaw 2000). The fact that Jatropha

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may grow and produce on marginal soil not suitable for food crops makes it ideal for use as energy or fuel source. Besides biodiesel production, the seeds of Jatropha provide proteins, which have a descriptive history in both nutrition and therapeutic applications (Mandal and Mandal 2000). From a nutritional perspective, seed storage proteins have always been major players in supplying global protein needs and food energy (Rosegrant et al. 2001; Steinfeld et al. 2006). The larger need for proteins in the livestock sector has accentuated the search for new protein sources that do not conflict with human food security interests. In the current situation, oilseeds able to produce on marginal soils are the potential and preferred choice for protein and other nutrients for livestock, provided they would be free of toxic and anti nutritional factors. The wide adaptability of Jatropha to grow under diverse agro-climatic conditions, marginal lands, thin soil, semi-arid as well as humid conditions theoretically ensure no competition with food crops (Rao et al. 2008). Moreover, the expected large production of biodiesel from Jatropha seeds will result in the availability of high amounts of pressed cake from seeds and kernel meal as by-products, which are rich in proteins of high quality. Unfortunately, the Jatropha's press cake is toxic to animal, but non-toxic varieties exists and research on press cake detoxification is on-going. Thus, in a close future, Jatropha's press cake should be available for animal feeding as well. In addition, the press cake could also be a source for various bioactive molecules having a wide range of activities (Wang et al. 2007). From a pharmaceutical, industrial or agricultural prospective, *Jatropha* spp. are also a rich sources of phytochemicals. Jatropha proteins and peptides have been studied for their role in the plant metabolic activities and defence against predators as well as for their therapeutic and industrial potential. In the present review an attempt has been made to discuss (a) the quality of oil as a biodiesel source, (b) the nutritional quality of seed proteins (specially for animals), (c) the chemistry, biological role and potential application of biologically active cyclopeptides, and (d) other usefulness of *J. curcas* plant parts in our daily life. It is hoped that the state-of-the-art information provided here will stimulate further research and development leading to more intensive, efficient, and sustainable utilization of Jatropha.

Biodiesel

Jatropha, which is believed to be native of Central America (Ratree 2004), belongs to the family Euphorbiaceae. Every part of this plant has its own uses. In the present day context, the major part that is economically important is the seed from which biodiesel can be produced. The utilization of Jatropha oil as a new source of fuel for diesel engine has tremendous scope in contributing to alleviate the pressure on energy resources (Saikia et al. 2009). Jatropha oil can be obtained from seeds by mechanical or solvent extraction with hexane (a non polar solvent) for 6–8 h in a Soxhlet. The extracted oil is then filtered and excess solvent is removed by using a rotary evaporator at 40°C. Finally, the crude oil is stored in a freezer at −2°C for subsequent analysis (Emil et al. 2010). The physicochemical properties include the amount (%) of fatty acid, iodine value, peroxide value, saponification value, viscosity, calorific value, cetane number, flash point, etc. It was found that the values of these properties are significantly different for the crude Jatropha oil compared to the fossil diesel used in diesel engines. This is only because of the presence of higher unsaturated fatty acids like oleic (42.4–48.8%) and linoleic acid (28.8–34.6%) (Emil et al. 2009, 2010). Other major fatty acids of Jatropha oil are the palmitic and stearic fatty acids. As the proportion of oleic and linoleic acids is higher, the Jatropha oil can be classified as oleic-linoleic oil. Physicochemical properties differing from recommended standards may result in poor atomization, coking tendency, carbon deposits and wear. These unwanted features were generally experienced in most of the tests that adversely affects the durability of an engine. It has been reported that the high viscosity and low volatility of vegetable oil (including crude Jatropha oil) are generally observed to be the major drawbacks for their direct injection in diesel engines (Prasad et al. 2000). The high viscosity of vegetable oils cause an increase in smoke levels and the low volatility of the vegetable oils result in oil sticking of the injector or cylinder walls causing deposit formations, which interfere with the combustion process (Sahoo and Das 2009). After several tests with crude vegetable oils for several hours (200 h), it was concluded that as far as power output, thermal efficiency and lubricating oil data are concerned, the 1:3 (v/v) blend of soybean oil and sunflower oil with diesel fuel performed satisfactory (Schlick et al. 1988). However after 200 h of operation, combustion examination of several parts revealed heavy carbon deposits in the combustion chamber, tracers of wear on piston rings as well as on the plunger and injector tips, slight scuffing of the cylinder liner and uneven spray from nozzles (Schlick et al. 1988; Bari et al. 2002). These problems led the investigators to suggest that either different operating conditions or modification of vegetable oils could help in improving the conditions of the engines (Schlick et al. 1988). The transesterification of a vegetable oil to its methyl esters reduces its molecular weight and viscosity and increases its cetane number (Gerhard 1983). The transesterification process has been proven worldwide as an effective mean of biodiesel production and viscosity reduction of vegetable oils (Peterson et al. 1992). Transesterification is the process of reacting triglyceride with alcohol in the presence of a catalyst to produce glycerol and fatty acid esters. Temperature, catalyst type, alcohol to oil proportion and stirring speed have been observed to influence the transesterification process to a greater extent. A comparative study of the physicochemical properties of crude Jatropha oil and its methyl esters with fossil diesel has been carried out to know the actual status of Jatropha oil concerning its biodiesel performance (Singh and Padhi 2009) (Table 15.1). The study show that Jatropha oil can be used as a source of triglycerides for the production of biodiesel by esterification and/or transesterification. Although the biodiesel from refined vegetable oils meets the requirement of a high speed diesel oil, the production of biodiesel from edible oil is currently much more expensive than fossil diesel due to the relatively high cost of edible oil. Thus, there is a need to explore non-edible oils like that of Jatropha for the production of biodiesel as it is easily available in many parts of the world including India and is cheaper compared to edible oils.

Table 15.1 Comparison of fuel properties of Jatropha oil, Jatropha methyl ester and diesel

Property	Unit	Jatropha oil	Jatropha oil methyl ester	Diesel	ASTM D 6751-02	DIN EN 14214
Density at 15°C	Kg m^{-3}	918	880	850	875–900	860–900
Viscosity at 40°C	$mm^2 s^{-1}$	35.4	4.84	2.60	1.9–6.0	3.5–5.0
Flash point	°C	186	162	70	>130	>120
Pour point	°C	−6	−6	−20	—	—
Water content	%	5	Nil	0.02	<0.03	<0.05
Ash content	%	0.7	Nil	0.01	<0.02	<0.02
Carbon residue	%	0.3	0.025	0.17	—	<0.3
Sulphur content	%	0.02	Nil	—	0.05	—
Acid value	mg KOH g^{-1}	11.0	0.24	0.35	<0.8	<0.50
Iodine value	—	101	104	—	—	—
Saponification value	—	194	190	—	—	—
Calorific value	MJ kg^{-1}	33	37.2	42	—	—
Cetane number	—	23	51.6	46	—	—

Source: Singh and Padhi (2009)
ASTM: American Society for Testing and Materials
DIN: *Deutsches Institut für Normung* (German Institute for Standardization)

Nutritional Source

Both the toxic and non-toxic genotypes of Jatropha exist. Toxic genotypes are prevalent throughout the world while non-toxic genotypes exist only in Mexico (Makkar and Becker 2009). The seeds of *J. curcas* are composed of kernel and shell with an average ratio of 62.2:37.7. The kernel has higher crude protein (22–28%) and oil contents (54–58%) compared to the shell (4–6% crude protein and 0.8–1.4% oil) (Makkar et al. 1998). The seeds also contain antinutrients and toxic factors such as phytate, trypsin inhibitor, lectin, curcin and phorbol esters (PEs). Hence, the use of Jatropha meal and protein isolates prepared from toxic genotypes of Jatropha in animal nutrition is still restricted (Makkar and Becker 2009; Makkar et al. 1997).

Storage Proteins

The storage proteins in seeds are important for germination and also have important nutritional value. The storage proteins extracted from defatted kernel meals of both toxic and non-toxic genotypes revealed that the total protein content is ~89% (Osborne 1924). Glutalins, globulins and albumins shared a major proportion of total protein contributing 56.9%, 27.4% and 10.8%, respectively, whereas prolamins and non extracted proteins were present in minor quantities (0.6% and 4.3%, respectively). Gastric digestions of albumins and globulins by pepsin and pancreatin system had protein digestibilities of 64% and 61%, respectively, whereas a higher digestion rate (95%) was observed for glutalins. The glutelin fraction which forms >50% of proteins leads to low solubility of Jatropha protein (Selje-Assmann et al. 2007), which in turn decreases protein degradation in rumen when compared to soybean proteins. Thus, a high amount of rumen undegradable protein available post-ruminally can be utilized by gastric digestion. The ruminal and gastric protein digestions indicate the potential availability of Jatropha protein in both ruminants and monogastrics. However, the meal should be detoxified before it is incorporated into animal diets (Devappa et al. 2010). It has also been reported that defatted *Jatropha meal* (JM), which was obtained after oil extraction with hexane and defatted *Jatropha kernel meal* (JKM), which was obtained after solvent extraction of kernels (free of shells) have high protein content. The JKM contains higher protein content than JM. Non protein nitrogen represented only 4.7–5.0% of proteins in JKM (Makkar et al. 1998). The rate of digestibility of JKM proteins is high (90%) and the protein fraction has good amino acid composition (Makkar and Becker 2009). The amino acid composition of proteins is often used to define their nutritional quality. The amino acid composition of meals from both toxic and non-toxic genotypes of Jatropha was found similar. The levels of *essential amino acids* (EAA) except lysine were higher than that of the FAO reference and the EAA requirements for chicks and young pigs (Makkar et al. 1997, 1998, 2008; Devappa and Swamylingappa 2008). Similarly, the levels of EAA except isoleucine in Jatropha meal was higher or similar when compared to castor bean meal, and except for lysine, the amino acid profile is comparable with that of soybeans (Makkar et al. 1998). However, in JM and JKM, the presence of antinutritional factors and toxic factors restricts the utilization of these meals in animal nutrition (Makkar and Becker 2009; Devappa and Swamylingappa 2008).

Protein Isolates

Protein isolates are the concentrated forms of plant proteins, generally prepared by solubilizing proteins and removing non protein ingredients. The rate of protein digestibility of such isolates was also approximately 90% (Makkar et al. 1998; Devappa and Swamylingappa 2008). The EAA content (except lysine) of protein isolates was higher than those of FAO/WHO references considering 3–5-year-old children and the amino acid levels in the protein isolates were similar to those in the kernel meal. The calculated values for nutritional indices such as computed protein efficiency ratio (C-PER) (based on the EAA profile and protein digestibility analysis) for JM (1.1), JKM (1.72), protein isolates from JM (1.85) and protein isolates from JKM (2.16) were comparable to or higher than the reported C-PER values for regular animal feed ingredients such as corn meal (1.1), wheat flour (0.8), soy flour (1.3) and quality protein feeds (1.43) (Devappa and Swamylingappa 2008;

Angulo-Bejaranoa et al. 2008). This suggests that Jatropha proteins have good quality and could supplement or replace the conventional protein sources in animal diets.

Animal Nutrition

Most genotypes of Jatropha produce seeds containing several toxic factors such as phytates, trypsin inhibitors, lectin, curcin and phorbol esters (PEs), which makes their seed meal toxic to mice, rats and goats (Goel et al. 2007). The major organs that were affected in these animals were intestine, liver and kidney (Li et al. 2010). PEs were found to be the principal compounds responsible for meal toxicity as shown by feeding fish and mice with their purified fractions (Becker and Makkar 1998; Li et al. 2010). PEs are present in Jatropha meal at levels of 2–4 mg g^{-1} (Makkar and Becker 2009; Makkar et al. 1997).

In the past two decades, several studies have been carried out for the complete detoxification of Jatropha meals. In brief, trypsin inhibitors and lectin were completely deactivated by moist heat (Aderibigbe et al. 1997; Aregheore et al. 2003). However, toxic PEs could not be removed completely due to their stability to heat and chemical degradation (Chivandi et al. 2004; Martinez-Herrera et al. 2006; Devappa and Swamylingappa 2007). Recently detoxification of Jatropha kernel meal and protein isolate had been successfully achieved (Devappa et al. 2010). *The detoxified Jatropha kernel meal* (DJKM) and *detoxified protein isolate* (DPI) prepared from screw pressed cake have been added to fish diet at high level with excellent growth performance and no toxic effects at blood and tissue levels. The DJKM and DPI have high protein content (60% and 90%, respectively) and excellent amino acid composition and these preparations could replace at least 50% of the protein contributed by the high quality fish meal (65% protein) in standard fish diet. It has also been reported that the feeding of Turkey, pigs and broilers with DJKM and DPI resulted in growth response and nutrient utilization comparable to those obtained with concentrates prepared from conventional protein sources without any apparent signs of toxicity (Devappa et al. 2010). On the basis of the results obtained so far on fish and other animal species it has been suggested that the DJKM and DPI are suitable substitutes for fish meal or soybean meal for livestock diets (Makkar and Becker 2009). The meal from non-toxic Jatropha genotypes is free from PEs, but it contains trypsin inhibitors, lectins and phytates at the same levels as the meal from toxic genotypes. The nutritional quality of the non-toxic Jatropha meal, after heat treatment (to inactivate trypsin inhibitor and lectin), evaluated in fish (carp) and rat models, was found to be very high (Makkar and Becker 1999). The meal or the protein isolate obtained from the non-toxic genotype, after heat treatment, could be an excellent protein rich ingredient in feed of ruminant and monogastric animals including fish. Moreover, it has also been reported that along with the storage of proteins and oil, Jatropha seeds are also a source of carbohydrates and other minerals with livable antinutrients levels. The effect of some physical treatments (like soaking, germination and roasting) and some chemical treatments (like $NaHCO_3$, ethanol extraction and NaOH) were successful in inactivating the antinutrients (phytic acid, trypsin inhibitor activity, total phenols and saponins) (Abou-Arab and Abu-Salem 2010). In parts of Mexico (like in Veracruz State), seeds from non-toxic Jatropha genotypes are also consumed by humans, after roasting (Makkar et al. 1998), but the consumption of raw seeds is considered to produce cramps and uneasy feeling in stomach. The protein hydrolysate obtained from ground Jatropha cake have shown to be well solubilised and contained proteins at a rate as high as 71.69%, which is appropriate for further applications in human and animal food (Apiwatanapiwat et al. 2009).

Pharmaceutical Importance

Presently lot of research activities have shown that the cyclopeptides isolated from latex, seeds and roots of many plants possess various biological activities such as cyclooxygenase, acetyl choline esterase and tyrosinase inhibition (Yahara et al. 1989; Morita et al. 1994), immunosuppression (Morita et al. 1997), antimalaria (Baraguey et al. 2000), vasorelaxation (Morita et al. 2005) and cytotoxicity (Mongkolvisut et al. 2006). Jatropha species have been shown to be a rich source of bioactive cyclic peptides, which contain 7–10 residues with a high proportion of hydrophobic amino acids. There is a need to exploit the potential role of cyclic peptides from Jatropha for pharmaceutical applications (Devappa et al. 2010). The cyclic peptides isolated from *J. curcas* (*viz.,* jatrophidin and curcacyclines A & B) only are discussed below, emphasizing their chemistry in view of its potential in agricultural and pharmaceutical sectors.

Jatrophidin

Jatrophidin is an octapeptide isolated from the latex of *J. curcas* (Altei et al. 2008). The latex was partitioned with ethyl acetate, fractionated on Sephadex G15, eluted in solid phase extraction, and purified by HPLC to obtain jatrophidin-I. The amino acid analysis, mass spectroscopy, and 1D/2D nuclear magnetic resonance (NMR) studies demonstrated that jatrophidin-I exists as two conformers of a cyclic structure (Gly-Trp-Leu-Asn-Leu-Leu-Gly-Pro) with the conformational equilibrium of proline residues between *cis* and *trans* forms, indicating that this peptide has more than one conformational state in solution. The isolates of jatrophidin-I had weak antifungal effect against the strains of *Candida albicans*, *C. krusei, C. parapsilosis* and *Cryptococcus neoformans* and moderate activity as an acetylcholinesterase inhibitor, when compared with the standard galanthamine.

Curcacyclines A and B

Curcacycline A was isolated from the ethanolic extract of *J. curcas* latex. It is a cyclic octapeptide ($C_{37}H_{66}N_8O_9$; MW 766.97). The amino acid sequence was determined to be cyclo-(Gly^1-Leu^2-Leu^3-Gly^4-Thr^5-Val^6-Leu^7-Leu^8). Curcacycline A displayed a moderate inhibition of (1) the classical pathway activity of human complement and (2) the proliferation of human T-cells (Van den Berg et al. 1995). Curcacycline B is a cyclic nonapeptide ($C_{42}H_{73}N_9O_{10}$; MW 863) isolated from the latex of *J. curcas*. The amino acid sequence was found to be cyclo-(Leu^1-Gly^2-Ser^3-Pro^4-Ile^5-Leu^6-Leu^7-Gly^8-Ile^9). The absolute stereochemistry of amino acids was shown to be *"L"* configuration. It contains mostly hydrophobic residues and one proline, thus differing from cyclic peptides previously isolated from the latex of *Jatropha* spp., which does not contain proline. The structure of curcacycline B was suggested to be a substrate for peptidylprolyl cis-trans isomerase (PPIase), as it has some structural features in common with cyclosporin A (inhibitor of cyclophilins A and B). Curcacycline B enhances PPlase activity by 60% at 30 μM based on an enzymatic experiment involving a human cyclophilin B and R-chymotrypsin rotamase, whereas no modification of cyclophilin B activity was observed in the presence of curcacycline A (Auvin et al. 1997). Curcacycline B from *J. curcas* possesses antimalarial activity (IC_{50} < 10 mM) against *P. falciparum* (Baraguey et al. 2001). Besides the activity of these cyclopeptides, the antibiotic effect of an alcohol extract from *J. curcas* leaves has been observed *in vitro* on *Escherichia coli* and *Staphylococcus aureus* (Zeng et al. 2004). The extract inhibited *E. coli* and *S. aureus* and the activity against *E. coli* was found to be larger than that against *S. aureus*. The poisonous effects of protein fraction, seed oil and ethanol extract from Jatropha seeds were evaluated for insecticidal activity against *Lipaphis erysimi* (Kaltenbach) (Li et al. 2004). The protein fraction did not show any significant effect to *L. erysimi*, while seed oil demonstrated strong contact toxicity. The molluscicidal efficacy of Jatropha seed extracts from Yunnan (China) and Mali (Africa) was compared by Cheng et al. (2001) and these authors did not found any difference of activity between the extracts from these distant countries. Actually, PEs have strong molluscicidal activity (Goel et al. 2007) and the content of PEs in Jatropha seed samples collected from different parts of the world have been of similar order of magnitude.

Other Traditional Uses

Apart from the above mentioned useful properties, Jatropha has many other economic uses. Its seeds and fruits are anthelmenthic, useful in chronic dysentery, thirst, tridosha, urinary discharge, abdominal complaints, biliousness, anaemia fistula and heart diseases (Nasir et al. 1988; Gubitz et al. 1999; Augustus et al. 2002; Akintayo 2004; Franke et al. 2004). It is also applied topically for rheumatism, herpes and pruritus. Jatropha leaves are used in traditional medicine against coughs, as antiseptics after birth, and food for the Tassar silk worms (Gubitz et al. 1999; Kinawy 2010). On the other hand the sap extracted from the leaves is used via external application to treat piles. In addition, the tender twigs of the plant are used for cleaning teeth (Kinawy 2010). The latex is useful for wound healing and other medical uses (Salimon and Abdullah 2008). The deoiled seed cake of Jatropha is suitable as substrate for enzyme production by solid-state fermentation (SSF) and also supported good bacterial growth and enzyme production (Mahanta et al. 2007). Traditionally, various solvent extracts of Jatropha have been taken orally with ripe banana to treat dysentery in adults. The sap from twigs is considered stypic and is used for dressing wounds and ulcers. The bark is rubbed with asafoetida and buttermilk is reportedly taken orally to relieve dyspepsia and diarrhoea. A decoction of bark is used externally for treating rheumatism and leprosy. The decoction of root bark is used to rinse mouth, to relieve toothache and sore throat (Goonasekera et al. 1995; Parotta 2001). The bark is also rich in tannin and produces a purple dye (Openshaw 2000). Moreover Jatropha can be used for erosion control, as living fence, ornamental plant or even as firewood.

Conclusion

Jatropha is a multipurpose plant with many attributes and considerable potential. Its seeds constitute a source of oil, proteins, carbohydrate and minerals with tolerable antinutrient level. The high seed yield of Jatropha oil compared to other vegetable sources is an advantage for selecting this oil to produce cost competitive products. The seeds of Jatropha are nutritionally promising and could allleviate protein malnutrition, which is a major public health problem in the developing world and is still unexplored. The seeds may thus be a good option due to their multipurpose features of Jatropha such as its high level adaptability to environmental factors, applicability of seed oil for biofuel production, and generation of productive value-added co-products.

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