BIOFUEL CROPS FOR DRYLANDS
CULTIVATION AND PROCESSING ISSUES

Technical Bulletin 1/2010




GR Rao, YG Prasad, M Prabhakar, I Srinivas, KV Rao, GR Korwar, B Venkateswarlu, AK Shankar, G Ravindra Chary and NN Reddy

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059
http://crida.ernet.in

BIOFUEL CROPS FOR DRYLANDS
CULTIVATION AND PROCESSING ISSUES

GR Rao, YG Prasad, M Prabhakar, I Srinivas, KV Rao,
GR Korwar, B Venkateswarlu, AK Shankar,
G Ravindra Chary and NN Reddy

भाकृअनुप
ICAR

Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059
http://crida.ernet.in

Citation :
Rao, G.R., Prasad,Y.G., Prabhakar, M., Srinivas, I., Rao, K.V., Korwar, G.R., Venkateswarlu, B., Shankar, A.K., Ravindra Chary, G. and Reddy,N.N. Biofuel Crops for Drylands: Cultivation and Processing Issues, Technical Bulletin 1/2010, Central Research Institute for Dryland Agriculture Hyderabad, 32p.

January, 2010
500 copies

Published by
Dr. B. Venkateshwarlu
Director
Central Research Institute for Dryland Agriculture
Santhoshnagar, Hyderabad - 500 059.
Phone : 040-2453 0177
Fax : 040-2453 1802 / 2453 5336
Web : crida.ernet.in

Designed & Printed at :
Balaji Scan Private Limited
A.C. Guards, Hyderabad - 4.
Ph. : 23303424 / 66107719

FOREWARD

Rapid industrialization coupled with population growth has increased the demand for different sources of energy *viz.,* coal, electricity (nuclear and hydro), natural gas and oil. Over the last four decades, per capita energy consumption (globally) has averaged about 1.5 toe (tonnes of oil equivalent) /person/year. As industrialization has progressed, per capita energy used has also increased, rising from a global average of 1.2 toe in 1966 to 1.7 toe person in 2006. Among the energy sources, oil is the most convenient (portable) source of energy. India with 3.2% consumption of the world oil production stands 6th among the top ten consumers. Hence, we import most of our oil requirements. The oil imports have cost the exchequer 2.72 lakh crores during 2007-08. With limited oil reserves and increasing demand for oil it is only pertinent to look for alternative sources. In India, bio-fuel from non-edible oil producing plants such as Jatropha and Pongamia are seen as potential sources that perform well under the limited resources. The Planning Commission gave an impetus to cultivation of tree borne oilseeds, as they yield nonedible oils suitable for biodiesel production. CRIDA has been engaged in Research and Development work on Jatropha, Pongamia and Simarouba for the last six years.

This Illustrative bulletin covers all aspects of these three TBOs based on CRIDA's experiences. I appreciate and complement the team for bringing out this timely publication and sincerely acknowledge the funding support from Rain Shadow Area Development Department, Government of Andhra Pradesh.

B. Venkateswarlu

(B. Venkateswarlu)
Director

CONTENTS

BIOFUEL CROPS FOR DRYLANDS
CULTIVATION AND PROCESSING ISSUES

Introduction

With the dwindling of fossil fuels, renewable sources like biofuels are now becoming alternative energy sources. Biodiesel is an important renewable source which has gained popularity recently due to its sustainability and low carbon emissions. Biodiesel is defined as the fatty acid alkyl esters of vegetable oils, animal fats or waste oils. It is a technically competitive and environmentally friendly alternative to conventional petrodiesel for use in compression-ignition (diesel) engines. Biodiesel has potential to become essential transport fuel during the transition from petrol and diesel to future fuel technologies over the next 30 years.

Although various plants such as sorghum, soybean, canola and other oil crops can be used to produce biodiesel, using them in large scale to produce fuel is not advisable as these are food crops and any large scale diversion of area under food crops to biofuels will cause a spurt in food prices and shortages. Particular mention may be made about the use of maize or sugarcane for production of bioethanol and oil palm or soya for biodiesel. Even the shift to non-food based biofuels such as algae, food waste, and other cellulosic-based fuels runs the risk of unintended ecological and social consequences. Moreover, these types of non food biofuel feed stocks need heavy quantities of water. Hence the use of non food plants, shrubs and trees to produce biodiesel is a prudent strategy and the development of agronomic practices and breeding of high yielding varieties for increased quality and quantity of biodiesel are the need of the hour. Nearly 85 m ha of India's 142 m ha net sown area is rainfed. Dryland agriculture is practiced in rainfed areas with relatively low rainfall and regular seasonal water deficits/droughts. Selection of suitable low input and viable biodiesel crops for these regions and other wastelands is necessary to maintain an optimum balance between food and fuel production.

The potential benefits from targeting non food trees and shrubs as biofuel feedstock crops in drylands, marginal lands and wastelands are manifold:

- increasing energy accessibility and safety

- reducing greenhouse gas (GHG) emissions thereby contributing to mitigation of climate change
- increasing income of marginal and small farmers
- Increasing employment in rural areas
- promoting energy self sufficiency

Non food tree based biofuel crops that can be produced with low water and fertilizer inputs on fallow or degraded lands, may have greater payback to the small and marginal farmers. However, the assumption that marginal and degraded lands alone can produce biofuel crops are too optimistic. There are a number of strategies for promotion of biofuels crops in the country. CRIDA had adopted a three pronged strategy to strengthen R&D on tree based biofuels in arid and semiarid regions.

(1) Promote Sustainable and Low-resource Intensive Feedstocks

Biofuels are a sustainable source of energy only if feedstocks are grown sustainably: feedstocks should be cultivated with biodiversity-friendly practices. This is possible when indigenous perennial species that need little inputs are preferred as feed stocks to be grown predominantly in polyculture or multi-year rotations over the energy intensive monocultures of annual crops. In this respect, CRIDA is attempting to produce biofuel crops with high-energy yields per hectare with low-input methods. Biofuel crops vary greatly in their requirements for soil types, fertilizer requirements and management practices. Hence, besides identifying superior high yielding germplasm, CRIDA is focusing more on developing agro techniques for these crops.

(2) Preserve Native and Essential Food-Crop Habitats

Biofuels will be biodiversity-friendly only if their cultivation does not intensify agricultural impacts, inflate agricultural conversion of native habitats or displace cropland essential for meeting human nutritional demands. Hence in compliance with UN and the Government of India's policy on biofuels, CRIDA's research on biofuels crops follows the strict thumb rule that the propagation and intensification of biodiesel crop cultivation should not threaten food grain production. Given the competition for good lands for grain crops, CRIDA's research is focused on evolving varieties and practices which enable growing biofuels crops only in degraded and wastelands and other marginal lands not put to agricultural use.

(3) Promote Net Carbon-Neutral Biofuels

Since there is an urgent need to lower GHG emissions, biofuels with lower CO_2 emissions become obvious choice. Biofuels are less polluting and release fewer GHGs than petroleum-based fuels. Hence, CRIDA's focus is on trees which are net carbon sinks that can maximize the energy output per unit input and obtain maximum economic yield per ha of land. Tree based biodiesel crops have the ability to re-capture GHG emissions and in turn contribute to positive carbon foot print.

In the light of above facts, the R&D experiences of CRIDA with Jatropha, Pongamia and Simarouba as sources of biofuel are discussed in the following pages.

JATROPHA

Jatropha is a genus of about 175 succulent species, shrubs and trees out of which some are deciduous, like *Jatropha curcas* L., from the family Euphorbiaceae. The name is derived from Greek (iatros = physician and trophe = nutrition), hence the common name physic nut. Jatropha is native to Central America and has become naturalized in numerous tropical and subtropical areas, including India, Africa, and North America. Jatropha was exported as a valuable hedge plant to Africa and Asia by Portuguese traders. The adult trees bear separate male and female flowers, and do not grow exceptionally tall. As with many members of the family Euphorbiaceae, Jatropha contains compounds that are highly toxic to animals that makes it unsuitable for animal feed. When the seeds are crushed and processed, the resulting oil can be used in a standard diesel engine, while the residue can also be processed into biomass to power electricity plants.

Jatropha is traditionally grown as a live fence around agricultural fields and not browsed by cattle. The oil content varies from 35 to 40 % in the seeds to 50 - 60 % in the kernel (Ginwal *et al.,* 2005). Seed yields under

cultivation can range from 1,500 to 2,000 kilograms per hectare, corresponding to an extractable oil yield of 540 to 680 litres per hectare (Rao *et al.,* 2009). The oil is used as illuminant, lubricant and in soap industry (Kaushik *et al.,* 2007). Jatropha oil cake is a rich source of nitrogen, phosphorous and potassium and can be used as organic manure. Jatropha oil is extensively used in soap industry due to its high saponification value (Divakara *et al.,* 2009). Jatrophine, an alkaloid present in latex is believed to have anti-cancerous properties. It is used to cure skin infections, dropsy, rheumatism and paralysis. Tender twigs used in cleaning teeth and juice are said to relieve toothache. Jatropha bark yields a dark blue dye, which is used for colouring clothes and fishing nets in the Philippines (Thomas *et al.,* 2009).

Botanical Description and Habitat

Jatropha is a diploid species with 2n = 22 chromosomes. Leaves are large green to pale green; alternate to sub-opposite and three to five lobed with a spiral phyllotaxis. It is a monoecious species with unisexual flowers. The flowers are formed terminally. Ten stamens are arranged in two distinct whorls of five each in a single column in the androecium. In the gynoecium, three styles with one ovule per locule are present. Fruit is a capsule. Flowering occurs in hot and rainy seasons and are insect pollinated. Fruits are harvested in the month of October and each inflorescence yields a bunch of 10 or more ovoid fruits.

Jatropha curcas is generally found in all parts of India and is commonly grown as a hedge around farmland. In Andhra Pradesh, it is distributed in the districts of Adilabad, Anantapur, Chittor, Guntur, Nizamabad and Medak. Jatropha grows over a wide range of arid and semiarid climatic conditions with an average annual rainfall between 480 to 2380 mm and average temperature range of 11 - 28^0 C. The plant has the ability to withstand extreme droughts and survive a light frost. For the emergence of

seeds, hot and humid climate is preferred. Therefore, fairly warm summers with rains are beneficial for proper germination of seeds. The flowering is induced in rainy season with reduction in temperature and plants bear fruits in winter. Jatropha grows well in shallow soils and is commonly found growing in gravel, sandy and clayey soils. It also comes up in low fertility and alkaline soils.

Package of Practices Developed at CRIDA

Direct Sowing

Seeds or cuttings are planted in the main field with the onset of monsoon. Two seeds should be dibbled at each spot. When the seedlings are 4 weeks old, weaker seedlings should be removed to retain one healthy seedling at each spot and removed seedlings could be used for gap filling. The recommended seed rate is 5-6 kg/ha. Main field is prepared by digging pits of 30x30x30 cm at 3 x 3m spacing. Seed should be sown at a depth of 2 - 3 cm. For vegetative propagation, cuttings of 3 to 4 cm thickness and 15 to 20 cm length are recommended.

Transplanting

Seedlings raised in nursery can be transplanted when they are 8 - 10 weeks old. Seedlings should be raised in 6"x4" size plastic bags by using sorted seeds. The bags should be filled with soil, organic manure and bio fertilizers viz., Azotobacter and Phosphobacteria (1 g each) and VAM (5g). Bio control agents viz., *Trichodermma viridi* and *Pseudomonas* (1 g each) are added in the pot mixture. One seed to be planted in each bag. After 3 months, the seedlings should be transplanted at the beginning of the rainy season. Optimum spacing is 3 x 3m which accommodates 1111 plants/ha under irrigated conditions. On the other hand 2 m x 2 m spacing is recommended for rainfed conditions which accommodates 2500 plants/ha. In agro-forestry block plantations under rainfed condition the recommended spacing is 4m x 2m.

Fertilizer Use

Before transplanting 2 Kg organic manure, 10g urea, 120 g single super phosphate and 16 g muriate of potash should be applied in each planting pit as a mixture. It should be supplemented with bio fertilizers like Azotobacter (5 g), Phosphobacteria (5 g) and VAM (20 g) and bio control agents like *Trichoderma viridi* and *Pseudomonas* of 5 g each per pit. Second dose of urea should be applied 30 days after planting at the rate of 10 g/ plant. From second year onwards application of N, P and K at 20g, 120g & 60g respectively, per plant gives better growth and seed yield.

Pruning

Nipping of the branches should be done between 90 and 120 days after planting at 25 cm height from ground level. The top should be cut off cleanly so that it can produce 8-12 side branches. Initial pruning should be done when leaves shed at 6-7 months age and successive prunings to maintain minimum of 30 branches with flowers or fruits at every 9-month interval. Pruning is recommended upto 2 years to develop good canopy and for enhanced yield by increased fruit bearing area. During rest period (Leaf fall: January- February) branches are cut back at a height of 0.45 m from the ground level. In the second year, each side branch should be cut off at two-third length with one third remaining, to induce

Pruned plant

Regrowth of pruned plant

bushy canopy. This practice resulted in 30-40 % increased fruit yield when compared to non pruned plants at CRIDA. Light harrowing before monsoon is beneficial to check weed growth. Around 3-4 weedings are recommended in the first year of establishment for good growth of Jatropha plants. Growing of intercrops is possible during first two years, if the spacing followed for Jatropha is 4mx2m or 3m x 3m and soil conditions are good.

Pests and Diseases

Jatropha is infested at different stages with a number of insect pests and diseases that cause damage both in the nursery and in plantation (Prabhakar *et al.,* 2008).

Leaf webber damage

Webber: The larvae of inflorescence webber and capsule borer, *Pempelia morosalis* (Pyralidae: Lepidoptera) occur in groups and feed on leaves, inflorescence and tender buds by making silken webs. The damage is severe on inflorescence and fruits. The seeds in the affected fruits are damaged resulting in heavy yield loss. Jatropha is an indeterminate crop and flowers many times a year depending on climate and availability of soil moisture. Peak incidence of webber is recorded in February-March and August-September, coinciding with flowering. The number of webs per plant ranged between

Red hairy caterpillar (*Amsacta albistriga*): The pest is a polyphagous defoliator, mainly occurs in July-August. It is a sporadic pest in some areas while endemic in certain locations. Adult moths emerge with the onset of the monsoon rains. Grown up larvae are covered with reddish brown hairs all over body. The pest is

Red hairy caterpillar

migratory in nature and moves from field to field. Intercrops like pulses grown in Jatropha plantations are also attacked and depending on severity of pest attack, can necessitate their re-sowing.

Coccids: Infestation by soft scales *Megapulvinaria maxima* (Green) (Coccidae: Hemiptera) causing white scabs on leaves and twigs are common. All stages except the newly hatched nymphs are sessile. Movement of ants on the plants is the first indication of scale infestation. *M. maxima* incidence is observed from August to February with peak infestation in October and November. Infested plants often show black sooty mold.

Infestation of coccids

Leaf miner: Incidence of leaf miner is recorded year round. The larvae form mines/galleries in leaves and feed on the leaf tissue and cause papery white appearance of the damaged part. A number of leaf mines coalesce and reduce the photo-synthetically active portion of the leaf. It is a regular pest in nurseries.

Damage caused by leaf miner

Rood borer: The pest is active as summer period begins with increased water stress. The pest is a stand reducer as it can lead to death of yielding plants. Grubs tunnel into the main root leading to withering and death of plants. Grubs have strong and dark mouthparts and thorax and

Damage caused by root borer

abdomen are soft, whitish, cylindrical and segmented in appearance. Grubs can grow up to 25-30 cm in size. They appear to have a long life cycle as the grubs survived for about 6 months in the laboratory conditions. Often infestation goes unnoticed till withering symptoms are seen. The pest at present is not widespread in occurrence but has the potential of destroying established plantations, where it occurs.

Spotted bug

Spotted bugs: *Scutellera nobilis* (Fabricius) and *Chrysocoris purpureus* (Westwood) (Scutellaridae: Hemiptera) are the two species of bugs found infesting *J. curcas.* Both the bugs are metallic blue-green in colour with 8 *or* 12 black spots on the dorsal side of thorax and abdomen. Their incidence is noticed throughout the year, but high population is recorded during August-November and the mean number of adults per plant ranges between 2 and 15. Eggs are pink in colour, found in groups on the leaves. On hatching, the pale red grubs with black patches on thorax move all around the plant in groups and suck sap from leaves, flowers and fruits. Feeding on inflorescence caused premature flower drop. Attack on fruits left pinholes, which further lead to rotting of the rind and eventually fruit drop.

Thrip Damage

Thrips: *Retithrips syriacus* (Mayet) (Thripidae: Thysanoptera) occur as colonies on leaves and tender fruits. Nymphs are reddish in colour and can be mistaken for spider mites. Adult thrips are black or dark brown in colour. Adults and nymphs cause damage by scraping the epidermal tissue and suck sap from leaves and fruits, resulting in white patches, which are visible from a distance. The damaged portions on the fruits turn into black patches and often lead to secondary infection of powdery mildew. Severe

foliar infestation results in premature leaf drop. It occurs all through the year except March and April. Peak incidence is in May-June and again in November-December. The mean number ranges between 35 to 250 and adult nymph ratio is 3.2: 29.4. Heavy rains during July-August diminishes their population and the plants recover their natural vigour.

Stem girdler: *Oncideres limpida* (Cerambycidae: Coleoptera), the twig girder, is one of the serious pests observed on *J. curcas*. Branches close to ground at 2 feet height and having thickness between 12 and 21 mm are the worst affected. The adult beetle chews a continuous notch girdling the twig. The girdles are similar to that made by a saw and the ends appear gnawed almost straight across with a faint rounding. The girdled twig soon dries out and breaks off; and the larva develops inside the fallen twig on the ground. The incidence of girdler is recorded mainly during October - November. The number of affected branches on each plant between 2 to 8 and about eight percent of the plants in the experimental block are found affected.

Stem girdler damage

Termite: It is observed mostly during January-June. Termites feed on cellulose material making the plant hollow and infestation usually starts in the beginning of summer. They make galleries filled with mud on the main stem and branches starting at the collar region. Feeding by large number of termite workers renders the affected plant parts hollow resulting in death of plants.

Termite damage

Tips for Pest Management

- Follow clean cultivation practices in the plantation
- Remove logs and decomposing plant material as they can harbour termites, stem girdler larvae and woodborer adults
- Destroy termite mounds as they develop within the plantation and in the vicinity to the extent possible. If infestation of termites is severe, apply chlorpyriphos 20EC @ 2.5ml/l (0.05%) on affected plant parts and @10ml/l (2%) to the soil.
- Plants infested with woodborer show wilting symptoms. Affected plants lodge and break easily as the main root and stem are rendered hollow due to feeding by the grub from inside. Prophylactic measures for preventing infestation include: better water management of plants especially in shallow soils with the onset of summer as stressed plants are more likely to be infested; and monitoring for metallic beetles on logs and plants. Trunk sprays with carbaryl @ 2g/l starting in February and application of carbofuran or phorate granules @ 3-5 g / plant mixed with sand at 1:4 ratio and apply to moist soil in the basins all around the plant away from the main stem affords some protection. Soil application of *Metarhizium* formulations @ 2 kg mixed in 100 kg of FYM and applied at the base of each plant after the onset of monsoon.
- If infestation of leaf miner exceeds 50%, apply neem seed extract (5%) 3-4 times at 7-10 days interval
- With the onset of monsoon, incidence of red hairy caterpillar is expected particularly in light soils and endemic locations. Adult emergence in the area can be monitored with the installation of light traps. Management of this pest is best done on a community basis and a combination of strategies. Collecting and killing of adult moths on a community basis is highly effective. Vegetative traps with twigs of *Calotropis* or *Ipomea* or planting cucumber all around the boundary can prevent migration of the grown up larvae and facilitate destruction of the pest. If necessary make a deep trench all around and apply folidol 2% or quinalphos dust 1.5% @ 20-25kg/acre. When defoliation is severe, apply foliar spray of carbaryl @ 3 g/ l.

- Webber infestation can be managed by application of neem seed extract @ 5% or if the infestation is severe with foliar sprays of chlorpyriphos or quinalphos @ 2 ml or dichlorvos @ 1 ml / l.
- Sucking pests like bugs and thrips can be managed with acephate @ 1 g or dimethoate @ 2 ml / l.

Genetic Improvement and Breeding

In spite of numerous favourable attributes of Jatropha, very little of its actual potential is realized mainly due to lack of genetic improvement programmes. Since Jatropha has adapted to a wide range of edaphic and ecological conditions, considerable genetic variability exists which can be exploited through breeding. Towards exploiting this variability, conservation and evaluation of Jatropha germplasm was taken up through collection and field evaluation, progeny trials, genetic analysis of variability, broad sense heritability and genetic advance.

Oil content, 100 seed weight, female to male flower ratio and seed yield showed higher heritability than other characters. Hence these characters can be viewed as best gain characteristics for Jatropha more so because of their strong genetic control and a wide range of variability. Other characters like total number of flowers, days taken from flowering to maturity showed low heritability and appear to be more influenced by environmental factors. Yield and plant height showed maximum advance indicating that the progress in shifting the genotypic mean and gene frequencies of yield and plant height in the population could be achieved in the desired direction by selection. There are two types of relationships of yield of Jatropha with flowering and fruiting phenology : i) A positive influence which is genetically and physiologically manifested because the longer the fruit takes to mature there is more time for seed filling ii) An indirect negative influence of the long maturity period is its vulnerability to higher flower and fruit drop in addition to attack by external abiotic and biotic factors.

The following are the salient findings on Jatropha research at CRIDA

- **Germplasm:** 161 wild and 24 elite accessions have been collected from across the country and are being evaluated under multilocational trials. In wild accessions, three promising genotypes on the basis of seed yield during 3rd year are RRL-NL-Mon-1105-C-1 (1146 g/pl), RRL-ASM-Bong-0206-C-2

(1114 g/pl), CRIDA-AP-Vishak-0206-C-19 (1001 g/pl) and in Elite CRIDA-JR-06 (994 g/pl), CSMCRI-OR-Ganj-1205-C4 (642 g/pl), CRIDA-JL-06 (641 g/pl) are the promising ones.

- At the end of fifth year, the average seed yield was 2.7 t/ha under rainfed conditions in alfisols receiving 739 mm rainfall annually. Intercropping was possible only up to 2nd year.
- **Spacing & Fertilizer trial:** Optimum seed yield was recorded with a spacing of 2 x 2 m and fertilizer application of N135+P300g/plant at the end of second year. (337.5 kg N and 750 kg P per ha)
- **Pests:** Common pests observed were stem borer, red hairy caterpillar, stem girdler, spotted bug, leaf webber, leaf miner, coccids, thrips & termite.
- **Pruning:** Pruning at 45cm from ground level showed enhanced seed yield (Table 1).
- **Breeding programme:** Out of 326 intraspecific (*J.curcas*) crosses attempted, seventeen crosses in elite germplasm & five crosses in wild germplasm resulted in 100% fruit set. In remaining crosses, the fruit set varied from 40-70%.

Crossing programme in Jatropha

Fruit set after crossing

- **Progeny trial:** At the end of fourth year, four best accessions in Jatropha were identified out of 22 accessions under evaluation whose average seed yield ranged from 0.9 to 1.2 t/ha, after 3 years which needs further evaluation.
- **National trial-III:** 18 progenies received from the network partners were raised in the Hayathnagar research farm and are being evaluated.
- The oil content in the seed ranged from 30-39%.

Table 1: Effect of Pruning on Growth and Seed Yield in Jatropha during 3rd year.

Treatments	Plant Height (cm)	Collar Diameter (cm)	No.of Branches	Seed Yield (t/ha)
Control	265	13.22	97	0.27
30 cm from ground	230	15.34	175	0.80
45 cm from ground	245	14.89	197	1.10
60 cm from ground	260	14.87	169	0.48

Dr. Mangala Rai, Director General ICAR visits biodiesel experimental plots at HRF, CRIDA

PONGAMIA

Pongamia pinnata (L.) Pierre. (family : Fabaceae-Papilionoideae) commonly known as karanja is a medium-sized tree with a short crooked trunk and broad crown of spreading or drooping branches. It is considered to be a native of Western Ghats in India and occurs naturally in most parts of the Indian subcontinent. The tree is valued for shade, ornamental value, seed oil, fodder and green manure. The leaves, roots and flowers are reported to possess medicinal properties. The seeds of this tree contain oil. The potential of this oil as a substitute for diesel, fatty acid methyl esters

(FAMEs) have already been found suitable for use as fuel in diesel engines. The tree is adaptable to wide agronomic climatic conditions.

There has been expansion of Pongamia plantations in India during the last few years, mainly for its oil for biodiesel production and because of its impressive growth performance under tropical conditions. Pongamia can help in restoration of fertility especially in degraded soils owing to its nitrogen fixing ability. Tap roots of Pongamia are deep seated and mine water even from 10 m depth without competing with other crops. It is also a drought resistant and hardy tree. Seeds of Pongamia have about 30-35% oil and upto 27-28% oil can be expelled in crusher; the physical and chemical properties of the oil are almost similar to those of the diesel, though 'Conardson carbon' residue is higher. Due to high viscosity preheating is needed to start a diesel engine.

Alternate Uses of Pongamia

Historically, Karanja has been providing other resources vital to a farming community. This plant has been used in India and neighboring regions as a source of traditional medicines, animal fodder, green manure, timber and fish poison. There are various time tested uses of pongamia other than the new found biodiesel. It is recommended as a shade tree for pastures and a windbreak in tea plantations. The leaves are said to be a valuable lactagogue (promotes milk production in cattle) fodder, especially in arid regions. It is often intercropped with fodder grasses that grow well in its shade. Dried leaves are used in stored grains to repel insects. Biogas made out of fermented seedcake is used as kitchen stove fuel in rural villages. Furthermore, the waste pulp is used as an organic fertilizer, which provides good income to the rural poor. The oil is also used as a lubricant, water paint binder, pesticide, and in soap and tanning industries. The wood is yellowish white, coarse, hard, and beautifully grained, but not durable. Use of the wood is limited to cabinet making, cartwheels, posts, and fuel. The ash of the wood is used in dyeing.

Package of Practices

Pongamia can be propagated through seeds, cuttings and grafts. Seedlings should be raised in nurseries. Planting should be done after the seedlings attain a height of 60 cm (4-5 months of age). Seedlings should be planted in the main field with the onset of monsoon. It is necessary to dip the cuttings of 30 cm length and 4-5 cm diameter in 500 ppm IBA solution for

5 seconds to get higher rooting percentage. Pongamia can be successfully propagated through cleft grafting during December - January. One-year-old rooted cuttings or cleft grafted plants are planted in the field. Vegetatively propagated plants reduce the variation among population and increase the seed yields.

Cleft grafting

Pongamia is established by direct seeding or by planting nursery-raised seedlings or stump cuttings of 1-2 cm root collar diameter. Propagation by branch cuttings and root suckers is possible. Seed germinates within 2 weeks of sowing. Seedlings attain a height of 25-30 cm in their first growing season. Transplanting in the field should be done at the beginning of the next growing season when seedlings attain 60 cm height. Seedling survival and growth benefit from regular weed control and after care for the first three years after transplanting.

Planting is done during June - July. Pits of 45 cm x 45 cm x 45 cm are dug at a spacing of 6 x 6 m in case of graffts and 10x10m for seedings which accommodates 278 plants and 100 plants, respectively per ha. Farm yard manure @ 2 kg/pit is incorporated before planting. Regular watering should be done if necessary till the plants are established. When grafts are used for planting, the graft joint should remain above the ground.

A fertilizer mixture of 42 g Urea, 168 g SSP and 42 g MoP should be applied per plant while planting. Pongamia plants are hardy and can sustain heat and drought. Graft is the recommended planting material to reduce the gestation period, height and harvest cost. In addition, this facilitates more number of plants to be accommodated per unit area. Intercrops like castor, pigeonpea, black gram and green gram performed well in pongamia plantations at CRIDA, Hyderabad, till five years after the establishment of the pongamia plants.

Pongamia + Redgram

Pongamia+ Castor

Genetic Improvement Research at CRIDA

Pongamia Plantation

The future success of *P. pinnata* as a sustainable source of feedstock for the biofuels industry is dependent on the knowledge of the genetics, physiology and propagation of this legume. In particular, research should be targeted to maximizing plant growth as it relates to oil biosynthesis. If this plant is to become an emerging plantation crop, comprehensive studies on its physiology, agronomy, propagation, genetics and molecular biology are needed.

The following are the salient findings of Pongamia research carried out at CRIDA

- **Progeny Trial:** On the basis of growth parameters, four accessions (Acc-8, Acc-10, Acc-16 & Acc-18) of Pongamia showed superior performance out of 23 evaluated. Some accessions started fruiting at the end of the third year.
- **Spacing Trial:** Effect of various spacings (5x5m, 6x4m, 6x6m and 8x6m) have till now (at the end of fifth year) not shown any significant influence on intercrops nor the growth of Pongamia plants was affected by the intercrops (Table 2).

- **Kernel Yield:** Average kernel yield at the end of fifth year ranges from 0.7 to 2.9 kg/plant in grafted plants, thereby indicating precocity of grafted plants.

- Seedling origin plants started flowering during fifth year and the average kernel yield recorded ranges from 0.4 to 0.9 kg/plant. The oil content in the kernel ranged from 25 - 45%.
- Nutritional and hormonal spray of Paclobutrazol at 10g ai/tree and 1% Urea two times a year decreased flower drop, increased fruit set and pod yield

Table 2: Growth of Pongamia with different spacings & Intercrops after fifth year of planting

Spacing / Inter crop	Plant Height (cm)	Collar Diameter (cm)	No.of Branches	Canopy (cm)	
				EW	NS
6 X 4 m					
Castor	296	8.2	28	280.3	296.9
Horsegram	290	7.2	41	252.2	258.7
Redgram	324	8.6	40	307.3	314.3
Control (Sole)	353	9.5	47	346.6	343.3
6 X 6 m					
Castor	322	9.5	44	367.3	356.7
Horsegram	306	8.5	48	319.8	320.2
Redgram	306	8.2	44	301.2	309.7
Control (Sole)	322	9.2	52	332.8	342.0
8 X 6 m					
Castor	301	8.8	38	320.9	314.3
Horsegram	302	9.9	41	340.2	335.9
Redgram	282	8.1	44	287.1	269.8
Control (Sole)	337	9.5	57	324.0	348.3

Pests of Pongamia

Pongamia plantations are affected by several insect pests such as leaf gall midge, *Microdiplosis pongamiae, Myricomyia pongamiae;* leaf miner, *Acrocercopes anthracuris,* mealybug, *Pseudococcus* spp., bark eating caterpillar, *Indarbela tetraonis.,* unidentified twig borer and pod borer. Among diseases, incidence of leaf spot and blight caused by *Fusicladium pongamiae*, rust, *Ravenelia hobsoni* and anthracnose caused by *Cercospora pongamiae* and *Sphaceloma pongamiae* have been noticed.

Leaf galls

Microdiplosis pongamiae and *Myricomyia pongamiae,* cause greenish, hollow, polypoid, pedicelled galls on the upper surface of the leaflets starting with the new flush of leaves. Galls interfere with the normal functions causing curling and stunting of growth. Most leaf galls are not seriously harmful to the plant, and they may at most cause a few leaves to fall off early. Severe incidence can be controlled by foliar spray by systemic insecticide, dimethoate 30 EC at *2* ml/l together with an acaricide, kelthane at 3 ml/l prior to the onset of new flush of leaves before the start of summer.

Galls on new flush in Pongamia

Extensive gall formation on leaves

Leaf miner

The larvae of *Acrocercopes anthracuri* burrow in the tissue of leaves forming large mines that appear as irregular blotches over which the cuticle becomes whitish and tightly stretched. The surface of the leaf below it often becomes puckered. Leaf miner is not a serious pest and its damage can be ignored as it seldom causes yield loss. Several natural parasites regulate the pest and help in natural rejuvenation of affected trees.

Leaf miner damage

Mealybugs

Mealy bugs on twigs

The pest occurs during the summer months. Both nymphs and adults suck the sap from the plant parts especially terminal twigs causing drying up of growing shoots. Later sooty mould develops on the affected plant parts. The common method of control is to prevent the ascent of the nymphs up the trees by fastening a grease band on the trunks a few feet above the ground. Alkathene banding 25 cm width around the trunk prevents crawlers infesting the shoots. Trunk sprays with Neem seed exract (5%) or Neem oil (0.3%) with surfactant (2.5ml/15L water) can control crawlers.

Branch and twig borer

Creamy white saw dust heaped at the base of the trunk is symptomatic of the damage due to false powder- post beetle inside a bored branch or twig. Eggs are deposited in cracks, crevices, pores or old emergence holes in wood, or in tunnels made by the females. Larva burrows into the wood. It continues feeding and as grows to maturity, it burrows toward the surface and pupates. The adult emerges from the pupa and continues to tunnel to the surface. Adults leave the wood, mate, and then the females return to

Beetle damage

lay eggs. Exit holes and sawdust from beetles burrowing out are often the first symptom noticed. The grub bores inside the stem. Tunneling inside is marked with a pencil thick entry hole visible on the outside from which the excreta exudes. The pest seldom causes mortality in trees.

Bark eating caterpillar

The caterpillar of *Indarbela tetraonis* feeds on bark by making tunnels in the main trunk or branches. Neglected plantations are most prone to this dangerous pest. Eggs are laid in clusters of 15 to 20 directly on the bark. A female may lay nearly 2000 eggs. The full-grown larva is 1.5 to 2.0 inches long. Pupation takes place in the tunnel and lasts about 3 weeks. The life cycle in India is annual with moths emerging in May-July and larval activity is from June-April. The moth has the forewing with rows of dark rusty red spots. The attack by this pest is characterized by the presence of long-winding, thick, blackish or brownish ribbon-like masses composed of small chips of wood and excreta, both of which intermix with the help of adhesive material secreted by the caterpillar, which bores into the bark of the trees and remains in the tunnels dug into the sap-conducting tissues. By continuously devouring the tissues, it tunnels through the stem and branches. This injury weakens the stem, resulting in drying of the branches and finally of the tree itself. Shelter holes are seen particularly at the joints of shoots and branches. Injecting kerosene oil or petrol in the pest infested holes after cleaning the frass and plugging them with cotton or wet soil during February-March and September-October can check damage. In case of severe infestation, the pest is controlled with trunk sprays of Carbaryl 50 WP @ 3 g/l.

Larva of bark eating caterpillar

Larval gallery on stem

Pod borer

Round holes of 1-2 mm diameter seen on the pod at one of the corners preferably towards the pedicel end indicate damage by the pod borer. Deep purple coloured larvae feed inside the pods devouring the kernels. Total seed loss is observed in some of the affected pods. The pest is active throughout the year and is a major yield limiting factor. The pest is carried to storage with the larvae continuing to feed and damage the kernels from inside. Continuous monitoring for pod borer incidence is required in managed plantations as the pest is active during the pod development stage starting April-May to next February (11 months). The pest is difficult to control because of this long development period. Early detection of pod damage coupled with need based sprays with insecticides such as dichlorvos @ 1 ml/liter or acephate @ 1g/liter or carbaryl @ 3 g/liter may reduce the severity of losses. After harvesting, pods in bags may be sprayed with malathion.

Diseases

Leaf spot and blight caused by *Fusicladium pongamiae* leads to severe leaf deformities. Leaf blotch disease caused by the fungus *Microstroma pongamiae* is characterized by white to cream coloured spots giving a yellowish appearance to the leaves. Rust caused by *Ravenelia hobsoni* leads to chestnut brown teliospore heads on the lower surface of leaves. Anthracnose caused by *Cercospora pongamiae* and *Sphaceloma pongamiae* results in spots on leaves, tender shoots and pods resulting in severe damage and defoliation in young seedlings and trees. In severe cases, disease control is achieved by foliar spray of carbendazim 2 g/l or dithane-Z-78 @ 2g/l during July-September. Wettable sulphur @ 1 g/l can check the foliar diseases.

Leaf spot symptoms

Leaf blotch symptom

SIMAROUBA

Simarouba glauca commonly known as aceituno, paradise-tree or bitter wood, is an important tree species growing in the forests of Central and South America. National Bureau of Plant Genetic Resources (NBPGR) first introduced it in 1960s at its regional Research Station at Amravathi, Maharashtra. Simarouba is indigenous to the Amazon

rainforest and other tropical areas in Mexico, Cuba, Haiti, Jamaica and Central America. It grows up to 20 m high and has a trunk 50 to 80 cm in diameter. It produces bright green leaves 20 to 50 cm in length, small white flowers, and small red fruit. It grows well up to 1000m above sea level in all types of well drained soils (pH 5.5 to 8) and establishes in places with 250 mm to 2500mm annual rainfall and temperatures up to 45^{o}C.

The tree is hardy and can effectively withstand dry conditions; it can be planted in areas where plants of economic value cannot be grown. About 200 trees can be accommodated in one hectare. It produces fruits similar in size, shape and colour to olives. There are two varieties: one produces greenish white fruit and the other violet to black fruits. The tree starts flowering during December and bears fruits in January and February. The fruits are ready to harvest in May. Though the tree commences bearing fruit from the fourth year of planting, economic yields (20 kg fruits per tree) can be harvested only from the 10th year of planting. The average yield of fruit from a hectare of a 10 year old plantation will be about 6,000 to 8,000 kg.

Ripen fruits of Simarouba

Simarouba Oil as Biodiesel

Oil derived from seeds of this tree has a new found use as a biodiesel which has sparked the interest in the cultivation and improvement of the tree. The filtered crude oil can be used to blend with diesel upto 5-10%. The surplus oil produced can be subjected to trans-esterification to manufacture biodiesel, a 100% substitute for diesel. The sugar rich fruit pulp can be used in the manufacture of ethanol. The oil-cake, fruit pulp, leaf litter, and waste wood can be used to generate biogas. The shell and waste wood can also be used in thermal power generation. The lignocelluloses contained in the biomass can be used as feedstock for manufacturing second generation biofuels.

Alternative Uses

All parts of the plant namely, seed, shell, fruit pulp, leaf, leaf litter, branches, stem, bark, and root are useful in the production of food, fuel, manure, timber, medicine. Simarouba seeds contain 60-70% oil that can be easily refined, bleached, deodorised and fractionated. It is suitable for edible and non-edible purposes. In some developing countries, it is used to manufacture of vanaspati, vegetable butter and/or margarine. The solid fraction rich in stearic and palmitic acids can be used as coco-butter substitutes (CBS) or coco-butter extenders in confectionery and bakery industries. The fruit pulp contains 13% sugars that can be used in the preparation of squash, beverage and jam. The timber is used for light furniture, toys, packing material, pulp and matches. This environment friendly tree is ideal for watershed areas, well suited for soil and water conservation and wasteland reclamation.

Cultivation

Its cultivation depends upon the rainfall distribution, waterholding capacity of the soil and sub-soil moisture range. The tree is able to withstand a temperature range of 40-45 ^{0}C. It can be cultivated in all the tropical regions of the world. It has a wide adaptability in terms of altitude requirement since it can be grown from 0-1500 meters above sea level. Simarouba can adapt to varying soil conditions, from sandy, lateritic, gravelly to black soils and with a pH ranging from 5.0 to 8.5. It can grow in degraded soils which are very poor in nutrients and unsuitable for cultivation of other crops. It can grow in soil types with moderately good porosity. Topographically, it can grow in planes, hill slopes with shallow soil and undulating terrains. Simarouba requires 700-1000 mm rainfall for normal growth, the crop can withstand relatively long (6-8 months) dry spells in a year. In rainfed areas, 2-3 month old saplings have to be used for transplanting. Direct seeding

can be done in lands with minimum limitation for water. In nursery, a polythene cover of 12 x 20cm is filled with sand, compost and soil in equal proportions. Four freshly harvested and dried seeds per bag should be sown at a depth 1.0 cm below the soil surface. Watering frequently with proper drainage is essential as excess water causes damping off disease. Seeds germinate in 25-35 days. Seedlings that are 2-3 month old are fit for transplanting. Pits of 45 x 45 x 45cm are filled mainly with top soil.

Planting pattern can be suited to alley cropping, boundary planting, bund planting, block plantations, or as avenue trees. Alley cropping with regular crops in interspace should have a spacing of 2 X 10 m. Planting a cluster of 2-3 seedlings in a pit is done at the onset of monsoon. Trenches and basins should be made to facilitate proper rainwater harvesting. Mulching of organic matter around the plant is done during post monsoon period. Lateral bud pruning is done till the saplings grow to about three metres height so that the trees grow tall and straight. This gives space for operations in intercrops in a Simarouba based agroforestry system. The high yielders should be retained after 5-6 years of planting, the low yielders are cut and the wood can be used for timber. After spreading of the canopy, shade loving crops or fodder crops can be grown as intercrops to get additional income and to prevent weed growth. Pruning of unwanted and criss-cross branches is done in June-July months to get better yield. In a typical biodiesel block plantation for oil production, no intercropping should be done. A spacing of 6 m x 6 m should be followed. Female and male plants should be maintained in the ratio of 10:1 and should be arranged in proper geometry in block plantation for effective pollination.

Salient Findings of Simarouba Research at CRIDA

- **Fruit Yield:** Dry fruit yield in grafted plants of Simarouba at the end of fifth year ranged from 5.2 to 14.8 kg per plant at the spacing of 6 X 6m. The oil content in the seed ranged from 62-66%.
- **Intercrops:** Intercrops were successfully taken without drastic reduction in the yield of Simarouba fruits till fifth year.
- **Pests:** Termite, bark eating cater pillar and leaf webber.

Table 3: Growth and yield in Simarouba at the end of fifth year with 6 X 6m spacing

Cropping System	Plant Height (cm)	Collar Diameter (cm)	No.of Branches	Canopy (cm) EW	Canopy (cm) NS	Dry Fruit yield (Kg/tree)
Simarouba sole crop	431	14.26	144	469.96	482.07	6.08
Simarouba+Castor	411	14.57	153	474.28	475.37	5.34
Simarouba+Cowpea	398	14.06	146	438.45	447.73	7.86

Termite damage in Simarouba

Simarouba + Cowpea

Simarouba + Castor

Flowering

Fruiting

Harvested Nutlets

PROCESSING OF BIOFUEL CROPS

The salient research findings of work done at CRIDA on oil extraction technology from biofuel crops are summarized below.

Method of Oil Extraction from Seeds

To prepare biodiesel, the oil is expelled from the seeds through Processes of solvent extraction, enzymatic extraction, etc. If seeds are processed at village level in a decentralized way by oil extraction in small scale units, it will reduce the processing cost compared to the biodiesel manufactured at a large scale Industry. In other words, biofuel processing needs to be shifted to rural small scale/medium scale industries. This in-situ extraction process brings together the energy source and the consumer reducing unnecessary transport of fuel. The nutritent rich cake meal, which is a byproduct can be used as valuable organic fertilizer in village farms.

Processing of Jatropha and Pongamia seeds for biodiesel application involves two major steps which include expelling the oil from the seeds and preparing biodiesel through transesterfication process. Un fortunately there is no specific oil expeller available in the market for Jatropha and Pongamia seeds. Commonly used expellers for groundnut and other small seeded crops having high oil content, are normally used for extracting oil from Jatropha and Pongamia seeds. In addition to this, these seeds consist of more gums and wax when compared to other conventional edible seeds and obstruct cake movement inside the cage chamber.

Conventional oil expeller

Due to these reasons, only 20-24 % of the oil is extracted from the Pongamia seeds and 24-27 % from the Jatropha seeds making it uneconomical apart from oil loss (around 8-12%) through cake, which finally restricts the cake usage as bio fertilizers. The efficiency of the oil expeller depends on the compression ratio of the expeller and screw configuration which includes the angle of helix worm geometry etc

(Bargale and Jaswanth Singh 2000). Hence modifications are necessary in expeller mechanism to increase the oil recovery and reduce the gums and waxes so as to make the oil more engine friendly.

Apart from the low recovery of oil from these seeds, the specific energy consumption was around 450 W/kg of oil which was higher when compared to conventional seeds (Yaduvanshi et. al. 2007). Hence

Development of Mini Oil Expeller with Optional Design at CRIDA

In order to enhance oil expulsion, the screw configuration and compression ratio of the expeller was modified. The expeller is provided with a separate arrangement for varying the compression ratio. As the rheological characteristics of seeds vary with feed source, care should be taken to adjust the compression ratio for maximum expulsion. This is achieved by increasing the gap between the screw and the inner surface of the oil chamber at the feed end, thus facilitating the movement of crushed cake towards the choke-end along with the shaft unlike in conventional expeller in which the shaft is tapered at the outer end. This arrangement increases the radial stress on the material.

Mini Oil expeller designed by CRIDA

The expeller is designed to work at variable shaft speeds to test the best combination of the screw configuration and speed for maximum oil recovery and lower energy consumption. The barrel is made up of a series of single circular mild steel plates joined together using two hollow mild steel rods.. Between the plates, about 0.025 mm thick spacers/shims are provided to facilitate the flow of expelled oil during the pressing operation. Relatively large numbers of shims are provided in the plug section as compared to the ram section. This is necessary as maximum pressure is applied in this section and larger quantity of oil is expelled. High flow rate is also made possible with the provision of wider spaced slits to avoid its accumulation to prevent the possibility of back-flow towards the feed section.

The other modifications included the change in compression ratio of the oil expeller, variation of screw speed, variation in worm helix angle and cake breakers angle for higher oil recovery.

Performance of Modified CRIDA Oil Expeller

1. Studies on mini oil expeller revealed that optimum compression ratio of 18.5:1 at 45 rpm speed gave maximum oil recovery of 27 per cent with 27 per cent energy saving for Pongamia oil extraction when compared to conventional method. Maximum oil recovery of 29 per cent with 26 per cent saving in energy consumption is obtained at 20:1 compression ratio at 45 rpm shaft speed for Jatropha oil extraction.

2. The worm helix angle of the screw showed significant effect on oil recovery and specific energy consumption for oil expulsion from Pongamia and Jatropha seeds. Maximum oil recovery of 29.01 per cent with 290 W SEC (specific energy consumption) and 9 per cent saving in energy is found at 75^0 helix angle for Pongamia and 30.75 per cent oil recovery with 262 W SEC is observed at 65^0 helix angle for Jatropha oil extraction. Overall 11 per cent saving in SEC is observed at optimum helix angle for Jatropha when compared to the conventional helix angle.

3. It is found that 70^0 angle gave maximum oil recovery from Jatropha and Pongamia seeds. Overall, 38 percent of saving in energy is obtained with maximum oil recovery of 30.16 per cent for Pongamia extraction when compared to the conventional oil expeller. Similarly 39 percent of energy saving is obtained with 32 per cent oil recovery with Jatropha extraction.

Annexure-I

Comparison of Jatropha, Pongamia and Simarouba

Characteristics	Jatropha	Pongamia	Simarouba
Rainfall requirment	500-1000 mm	500-2500 mm	400mm–1000mm
Soil type	Well drained soils	Tolerant to water logged, saline and alkaline soils	Well drained soils with pH 5.5 -80
Nitrogen fixation capability	No	Yes	No
Land use compatibility	Wastelands, degraded lands, live fence, agroforestr y, green capping of bunds, shallow soils	Block plantation, field boundary, nala bank stabilization, wastelands, tank foreshore, urban avenue, agroforestry	Block plantation, agro forestry, alley cropping, wastelands, Urban avenue
Plant habit	Mostly bush, can be trained as small tree	Big tree but can be managed as a medium canopy tree by repeated pruning	Big tree evergreen up to 15 m height, polygamodioecious. Responsive to pruning
Leaf use	unpalatable to livestock	Less palatable to livestock, used as green leaf mulch	Not palatable, leaf litter is a good manure
Gestation for yield	Short, starts yielding during 3rd Year, attains maturity at 6th Year	Long, starts yielding after 4th to 7th year. Yield increase with increase in Canopy. Grafts 2-3 years	Seedlings: 6-8 years Grafs: 3-4 yeas
Harvesting method	Fruits to be plucked	Fruits to be collected	Hand Picking, shaking the branches and collecting fallen fruits
Seed yield /ha (at the end of five years at CRIDA)	1 to 3 t/ha (seed)	0.2 to 0.8 t/ha (kernels) Grafts	1.1 to 3.8 t/ha (nutlets yield) grafts
Oil content	27-38% in seed	27-39% in seed\ (kernel)	60-75% in seed
Protein	38%	30-40%	40-42%
Oil cake	As manure (4.4% N, 2.09 P, 1.68% K)	As manure (4.0% N, 1.0% P, 1.0% K)	As manure (8% N, 1.1% P, 1.2% K)
Fire wood	Not useful	Good as firewood, high calorific value 4600 K cal/kg	Moderate use as fuel
Furniture wood	Not useful	Can be used for low grade furniture from older trees	Can be used light furniture, toys, packing material and paper pulp and matches

Engine thermal efficiency	325%	31.2 %	32.5%
Brake specific fuel consumption	More than diesel	More than diesel	More than diesel
Viscosity of the Biodisel	3-5 Cs	5-7.5 Cs	3-6 Cs
HC emissions	Lesser than diesel	Lesser than diesel	Lesser than diesel
CO emissions	Lesser than diesel	Much lesser than diesel	Much lesser than diesel and Pongamia
NOx emissions	More than diesel	More than diesel	More than diesel

References

Bargale PC and Jaswanth Singh (2000) Development of a small capacity double stage compression screw press for oil expression. Journal of Food Engineering 43: 75-82.

Divakara BN, Upadhyaya HD, Wani SP and Gowda CLL (2009) Biology and genetic improvement of *Jatropha curcas* L.: A review. In press DOI: 10.1016/j.apenergy.2009.07.013, Applied Engery

Ginwal HS, Phartyal SS, Rawat PS and Srivastava RL (2005) Seed source variation in morphology, germination and seedling growth of *Jatropha curcas* L. in Central India. Silvae Genetical 54:76-80

Kaushik N, Kumar K, Kumar S and Roy S (2007) Genetic variability and divergence studies in seed traits and oil content of Jatropha (*Jatropha curcas* L.). Biomass Bioenergy 31:497-502

Prabhakar M, Prasad YG, Rao GR and Ramakrishna D (2008) Pests of economic importance on J*atropha curcas L*, a biodiesel plant in Andhra Pradesh. Entomon 33 (1) : 83-86)

Rao GR, Korwar GR, Shanker AK and Ramakrishna YS (2008) Genetic associations, variability and diversity in seed characters, growth, reproductive phenology and yield in *Jatropha curcas* (L.) accessions. Trees Structure and Function 22: 30. 697-709.

Thomas R, Sah NK and Sharma PB (2009) Therapeutic biology of *Jatropha curcas:* A mini review. Current Pharmaceutical Biotechnology 9 : 315-324

Yaduvanshi BK, Bhattacharya TK, Rajan P and Kundu K (2007) An investigation into Jatropha oil extraction through oil expeller. In Proceedings of National workshop on Biofuels Production, Methodologies, Utilization techniques and Challenges ahead, MERDO, Ludhiana : 197-204.





Central Research Institute for Dryland Agriculture

Santoshnagar, Hyderabad - 500 059

http://crida.ernet.in