Floral biology and seed technological aspects of *Jatropha curcas* Linn.

By

PUTTASWAMY, H

THESIS

Submitted in partial fulfillment of the requirement

for the degree

MASTER OF SCIENCE IN FORESTRY

Department of Forest Management and Utilization

COLLEGE OF FORESTRY

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

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ABSTRACT OF THE THESIS

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Declaration

I hereby declare that this thesis entitled **"Floral biology and seed technological aspects of *Jatropha curcas* Linn."** is a bonafide record of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society to me.

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CERTIFICATE

Certified that this thesis, entitled **"Floral biology and seed technological aspects of *Jatropha curcas* L."** is a record of research work done independently by **Sri Puttaswamy, H (2006-17-102)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara,

Mr. S. Gopakumar
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned members of advisory Committee of **Sri Puttaswamy, H.** a candidate for the degree of **Master of Science in Forestry,** agree that this thesis entitled **"Floral biology and seed technological aspects of *Jatropha curcas* L."** may be submitted by **Sri Puttaswamy, H.** in partial fulfillment of the requirement for the degree.

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Puttaswamy

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Dedicated to my

Parents, Teachers & Friends

Introduction

INTRODUCTION

With the exponential rise in petroleum prices and increase in demand for petroleum products around the world, it appears that the price of crude oil would remain high for a long time. India is not self-sufficient in petroleum and has to import about two thirds of its requirement. The current yearly consumption of diesel oil in India is about 40 million tones forming about 40 per cent of the total petroleum product consumption. Since the oil crisis of the 1970s and recognition of the limitations of world oil resources, most of the oil importing countries including India has been trying to develop alternative sources of energy for engines and domestic needs from other natural resources.

Biodiesel is one such option and many countries are taking initiatives in this direction. Biodiesel is an alternative diesel fuel, made from renewable biological sources such as vegetable oils and animal fats. It is biodegradable, nontoxic, has low emission problems and so is environmentally beneficial (Shay, 1993 and Krawczyk, 1996). Many studies have shown that the properties of biodiesel are very close to diesel fuel (Mittelbach *et al*., 1992 and Peterson *et al*., 1994). Therefore, biodiesel fuel can be used in diesel engines with little or no modification. Biodiesel has a higher cetane number than diesel fuel, no aromatics, no sulfur, and contains 10–11 per cent oxygen by weight. According to an estimate, even 5 per cent replacement of fossil fuel by biodiesel will help to save foreign exchange of over Rs 4000 crores annually (Bhattacharya and Joshi, 2006).

The worldwide production of biofuels (bio-ethanol and biodiesel) exceeded 33 billion litres in 2004, of which 31 billion litres per year was ethanol and 2.2 billions litres biodiesel. The biodiesel sector grew by 25 per cent per annum between 2000 and 2004. The production of biofuels is highest in Germany, with 50 per cent growth in 2004. France and Italy come second and third (Renewable Energy Policy Network, 2005).

Since India is not self-sufficient in edible oil requirement, focus is drawn on the production of biodiesel from non-edible oil seeds. The use of non-edible oils compared to edible oils is very significant because of the increase in demand for edible oils as food and they are too expensive to be used as diesel. In this context, the exploitation of Tree Born Oilseeds (TBOs) is given importance in the recent years. The sources of bio-diesel from TBOs are quite diverse in India. The important plant sources include *Hevea brasiliensis* Mull. Arg., *Jatropha curcas* (Linn.), *Ricinus communis* Linn*., Azadirachta indica A. Juss*, *Simaruba glauca DC, Pongamia pinnata* (Linn.) Pierre, *Madhuca indica* (J.F.Gmel.) *and M. latifolia* (J.F.Macbr.). Apart from these, *Calophyllum inophyllum* Linn*., Calotropis gigantia* R.Br*., C. procera* R.Br*., Avicennia marina* (Forsk.) Vierh*., Mimusops elengi* Linn., *Garcinia indica* (Thouars) Choisy., *G. gummi-gutta* (Linn.) and *G. cambogia* (Gaertn.) Desr. are also potential TBOs sources for bio-diesel production.

Among these, *Jatropha curcas* is recognized as most potential species for biodiesel production, owing to its short gestation period, hardy nature, high and quality oil content. The plant is valued for obtaining good amount of petro-fuel/biodiesel from its seeds (Bhattacharya, *et al*., 2005). The ratanjyot seeds contain up to 60 per cent oil with a fatty acid pattern similar to that of edible oils (Sujatha *et al*., 2005). The oil can also be used in soap and candle industries and its by-product glycerine can be used in the pharmaceutical industry.

Jatropha curcas is a shrub or small tree, belonging to the family Euphorbiaceae and is thus closely related to other important cultivated plants like rubber, castor, etc. It is commonly known as dravanti, janglirandi, ratanjyot and jamalghota in different states of India. It is known as physic nut and purging nut in English. Plant reaches a height of 3-8 m with stem up to 20cm diameter. It is cultivated in Central and South America, South-East Asia, India and Africa (Martnez-Herrera *et al*., 2006).The genus *Jatropha* has 176 species distributed throughout the World. Among them, 12 species are recorded in India. Two species

of *Jatropha* that are cultivated commercially include *Jatropha curcas* and *J. glandulifera* R.Br. *Jatropha curcas* is mainly promoted for bio-diesel because of higher oil content (up to 48%), whereas *J. glandulifera* is known for its beautiful flowers and oil content (up to 27%).

Studies on reproductive biology of forest trees is important in understanding barriers to fruit and seed set in natural habitats and to understand factors regulating the genetic structure of populations. It is an important pre-requisite for the effective exploitation of the economic potential of a species (Simmonds, 1962).

Though *J. curcas* has gained popularity as a biodiesel plant, no serious attempt has been made to investigate the phenological and seed technological aspects of this species growing in different localities in Kerala including Vellanikkara. Due to the paucity of such information very little efforts on its crop improvement and management have been attempted in this locality.

The present study was aimed at knowing the floral biology and seed technological aspects of *Jatropha curcas* – a tree-born-oil seed plant growing at Vellanikkara to know its potential for biodiesel production.

Review of literature

REVIEW OF LITERATURE

The crude oil requirement of our country is 105 million tons out of which only about 28-30 per cent is produced here and about 70 per cent is imported (Kumar *et al*., 2004). The only alternative is to produce our own fuel and meet the growing energy demand and also save on the huge foreign exchange that our country bears by importing crude oil. Biodiesel is identified as the substitute fuel for diesel.

Bio-diesel is a potential alternative for non-renewable fuels. It is obtained from virgin or used vegetable oil through trans-esterification. It is gaining importance in recent times in developing countries because it is bio-based, eco-friendly, biodegradable, non-toxic, renewable and sustainable fuel source. Its production is increasing in European countries. It can be mixed with ordinary diesel; it improves cetane rating and engine lubrication (Raju and Rao, 2006).The Central Government has instituted a National Bio-diesel Board to promote bio-diesel production.

2.1 Description

The name *Jatropha* refers to its medicinal value, in Greek, *Jatropha* means doctor and *trophe* means nutrition. *Jatropha curcas* is a large shrub/small tree belonging to the family Euphorbiaceae that grows up to a height of 4 to 5 m. *Jatropha* is a morphologically diverse genus comprising 160–175 species of trees, shrubs, rhizomatous sub shrubs and suffrulescent herbs (Dehgan, 1984). *Jatropha curcas* is well adapted to arid and semiarid conditions with low fertility and moisture demand. It can also grow on moderately sodic and saline, degraded and eroded soil. It reaches its maximum productivity by five years and live upto 50 years (Azam, *et al*., 2005).

2.2 Distribution

Jatropha curcas is a native species of Mexico and Central America, cultivated throughout the tropics and is sub-spontaneous in Mauritius and Seychelles (Baker, 1877). *Jatropha curcas* also grows abundantly in Central America (Bhattacharya, *et al*., 2005). The plant is able to thrive in a number of climatic zones with rainfall of 250-1200mm. In India, it is believed to have been introduced by Portuguese navigators in the 16th century. *Jatropha* is now found growing in all the parts of India and is commonly grown as a hedge around farm land (Srivastava, 1999). It has naturalized well in India with distribution in almost all states. Of late, Government of India has encouraged the use of Jatropha as a medium term alternative to energy security in the country through biodiesel.

2.3 Jatropha: A multipurpose tree

Jatropha curcas is a prominent species with wide variety of uses. Medicinal plant survey in Tamil Nadu showed that traditionally *Jatropha curcas* has been used as medicine (Rajendran *et al*., 2008). Seeds, leaves and bark are used in traditional medicine and for veterinary purposes. The oil has a strong purgative action and is also widely used for skin diseases and to cure the rheumatic pain. A decoction of leaves is used against cough and as an antiseptic after birth (Heller, 1996).The root bark is used extremely for rheumatism in Goa, and mixed with asafoetida and butter-milk is prescribed in cases of dyspepsia and diorrhoea in Konkan. The leaves warmed and rubbed with castor-oil are used by the natives as a suppurative. The green tender leaves are used for stopping bleeding. Aqueous extract of *Jatropha curcas* exhibited anti-HIV activity (Matsuse *et al*., 1999).

The oil is used as purgative, emetic and applied in rheumatism, herpes, and pruritus typically in Guinea. A report mentioned that “curcas oil” and latex have anticancer property (Horiuchi *et al*., 1987). *J. curcas* has high potential for

greening and eco-rehabilitation of wastelands as well as for bio-aesthetic reasons (Heller, 1996).

Jatropha curcas is a potentially valuable source of germplasm, possessing rare and beneficial characteristics such as drought resistance, photoperiod insensitivity, resistance to major insect pests and diseases, non-palatability to livestock and desired oil quality (Sujatha, 2004). *J. curcas* seed oil and its components possessed significant inhibitory effect on growth of the fungus, *Schizophyllum commune* after 7 days of inoculation and also nematicidal activity against *Meloidogyne incognita* (Singh, 2008).

Jatropha grows quickly, survives in poor stony soil, resistant to drought, can be grown on waste lands or barren and marginal agricultural lands where no irrigation facility is available. It does not compete with conventional food or feed crops for space and water, and thus it could be an ideal choice to make use of wasteland resources that are presently under utilized in tropical countries. Paroda and Mal (1989) listed *Jatropha curcas* as a plant suited to extreme environment, with tremendous industrial potential, but still under exploited. Jatropha is also planted as a hedge (living fence) by farmers all over the world around homesteads, gardens and fields, because it is not browsed by animals (Henning, 2004).

2.3.1 Curcas oil: Biodiesel

Seeds of Jatropha yield oil which is one of the best source of biodiesel; a renewable energy source. Biodiesel from *Jatropha* seed can be used in its pure form or can be blended with diesel to form different blends (Banapurmath *et al*., 2008). About 5 kg of *Jatropha* seed is provides 1 liter of curcas oil (Henning 2004). It is also used as a domestic energy. Several methods for oil extraction have been developed. In all processes, about 50 per cent of the weight of the seeds remain as a press cake containing mainly protein and carbohydrates. Considering

the wide and varied uses to which Jatropha can put, it is called as the "fuel of the future" (Kumar *et al*., 2004).

2.3.1.1 Benefits of biodiesel

Bangawal and Krishnaswamy (2004) reported that biodiesel reduces carbon dioxide exhaust emission by up to 80 per cent. It produces cent per cent less sulfur dioxide than petroleum based diesel. It reduces exhaust smoke (particulates) emission by up to 75 per cent. Biodiesel do not require any changes to the existing storage infrastructure and engine modification to use.

Biodiesel is much easier to handle and does not require mechanics to use barrier cream on their hands to protect the skin from cracking or redness. It is much less dangerous to put in a vehicles fuel tank as the flash point of biodiesel is ± 150º C as opposed to petroleum diesel which is at ± 50ºC. Biodiesel degrades about 4 times faster than petroleum diesel after spillage, with most of a spill broken down after just 28 days. It provides significant lubricity improvement over petroleum diesel fuel. So, engines last longer, with the right additive engine performance can also be enhanced. It also reduces the classic diesel engine "knocking" noise.

The literature pertaining to phenology, floral biology and seed technological aspects of *Jatropha curcas* and other related species are reviewed here under.

2.4 Phenology

Phenology is the study of periodic biological events in the animal and plant world as influenced by the environment (Schwartz, 2003). Information on phenology or periodic events is an essentiality for successful reproductive biology research. Jindal *et al.* (1985) opined that evolutionary dynamics of a species could be understood through phenology. Pioneer investigations in this field include

Croat (1969), (1975), Frankie *et al*. (1974), Gentry (1974), and Sasaki *et al*. (1980).

2.4.1 *Jatropha curcas*

Raju and Ezradanam (2002) stated that *J. curcas* is a perennial shrub or tree let which flowers during the rainy season with concentrated flowering from late July to late October in Vishakhapatnam. Each inflorescence, once it begins flowering, flowers daily, and the flowering lasts for 11 days. Bhattacharya *et al*. (2005) reported *J. curcas* flowers during July to September in the National Botanic Garden, Lucknow.

The flowering in *J. curcas* depends on the location and agroclimatic conditions. In Tamil Nadu, flowering and fruiting occurs almost throughout the year, but in northern India, flowers usually occur during August to December. Fruits mature in two months after flowering (Paramathma *et al*., 2004). In dry (dry-warm) river valleys of the Jinsha River, the Red River, the Lancang River and the Nu River, and in the semi-humid and semi-arid areas of the tropical South Asia, *J. curcas* bears fruits once a year, it blossoms in April and May, yields fruits in September and October, and its leaves fall from December to April of the following year (Kun *et al*., 2007).

2.4.2 *Azadirachta indica:*

Sharma and Khanduri (2007) carried out the phenological study on the twenty isolated trees of *Azadirachta indica* in and around Nainital in Central Himalaya. Detailed phenological records were made on four phenophases, namely (i) leaf sprouting, (ii) flowering, (iii) fruit setting and (iv) leaf and fruit drop, during two successive years from March 1998 to March 2000 at 3 to 4 weeks intervals. This study showed that the leaf initiation was started in the middle of February during both years. In the first fortnight of October the leaves turned

yellowish brown, and rapid leaf drop started from the end of October to the first week of November in both years. Leaf drop was completed by the end of November. In December and January, the tree remained completely leafless. *A. indica* showed concentrated leaf drop in early winter (October–November). This has resulted in the maximum trees completely leafless, leading to dormancy during severe winters (December to February).

The flowering started from April and last upto the end of May. The total period of flowering was about 47-51 days. Fruit setting started in the last week of May to the first week of June. They matured by the end of July. During August the fruits become brown and by the end of September they started dehiscing to disperse the seeds. The fruits were one to three-celled capsules with an average weight of 25.30 g. The average size of the fruits after full ripening was 3.8-3.5 cm.

In India, neem flowers from January to April, and the fruits mature from June to August (Gupta *et al*., 1996).

2.4.3 *Pongamia pinnata*:

Raju and Rao (2006) recorded leaf flushing and flowering season events in *Pongamia pinnata* by making periodical field trips to the study site (Lotugedda–Lambasingi Eastern Ghats and Visakhapatnam district). They found, leaf flushing occurs in March and flowering during April–May. A few individuals extend flowering into June. A few trees show flowering during the second season in October–November.

Flowering occurs during summer season in *Pongamia pinnata* (Raju and Rao, 2005).

2.4.4 Other species

Study on phenology in *Simaruba glauca* revealed that flowering period is from December to March every year (Hiremath *et al.,* 1996). Andrew (1995) studied phenology of Paradise-tree, *Simarouba glauca* in Hammock, South Florida. inflorescences usually appeared in March, mostly opening in early to mid-April. All flowering was completed by the end of April. Fruits appeared in May, ripening in late May and June. All fruits were gone by July.

Bahadur *et al*. (1994) studied the phenology of *Prosopis cineraria* and found that defoliation occurred from November to January and new leaves appeared in February. The flowering peaked from mid-April to mid-May, and the duration of flowering varied from 28-48 days.

Pushpalatha (2000) reported that the period of flushing and flowering in cashew varied among the accessions and majority of them started flowering during November to December. Damodaran *et al*. (1965) stated that the main season of cashew flowering was October to November, which commenced by the middle of September and continued until the end of February under Kerala conditions.

Field observations of sandal trees (*Santalum album*) showed that flowering generally lasted from June to October (Bhaskar, 1993).

2.5 Inflorescence and Floral morphology

2.5.1 *Jatropha curcas*

Jatropha curcas produce flowers in racemose inflorescence with dichasial cyme pattern. The flowers are unisexual, and male and female flowers are produced in the same inflorescence. Normally, the inflorescence produces a central female (1-5) flowers surrounded by a group of male (25-93) flowers. The average male to female ratio is 29:1. The inflorescence is monoecious with

protandry (Raju and Ezradaman, 2002). Bhattacharya *et al*. (2005) stated that the flowers of *J. curcas* are unisexual, regular, greenish white with about 17-105 male flowers and 2-19 females flower per inflorescence.

Chang-wei *et al.* (2007) reported that *J. curcas* produces flowers in racemose inflorescences with dichasial cyme pattern. The length of inflorescence is 5–9.5 cm, and the diameter 4.5–12.5 cm. Male flowers are small, odourless and unisexual. Sepals and petals are five each, free. Stamens are ten, diadelphous, arranged in two tiers of five each. The lower tier is free, while the upper is united. The anthers are yellow, dorsifixed. Female flowers are quite similar to the male in shape, but are relatively larger. Sepals and petals are relatively larger. The styles and stigmas are three in each and the later are bifid. The ovary has three carpels, each with a single locule producing one ovule. The flowers open in synchrony with male flowers.

2.5.2 *Azadirachta indica*:

Gupta *et al*. (1996) described the neem flower as bisexual and male flowers occur on the same individual, i.e., the species is 'andromonoecious'. Singh *et al*. (1995) described the ovary of neem flower as trilocular, having two ovules in each chamber; thus each ovary contains six ovules. Sharma and Khanduri (2007) described the tree as monoecious in nature. Flowers are white, zygomorphic, horizontal, open in cluster form, in large thyrsoid cyme-bearing terminal panicles. Calyx 0.50 to 0.75 cm long, tubular, with five short, rounded lobes, often split longitudinally in open flower. Petals 4, the place of 5th usually vacant, white and yellow, 1.5 to 2.0 cm long, clawed, unequal in breadth. Stamens 7, filiform, curved upward, longer than the petals; anther versatile. Disk one-sided. Ovary sessile, three celled; style simple, slender. Nectar cells absent.

Dayananda *et al*. (1997) stated each flower possesses 5 sepals, 5 petals and 10 stamens. The anthers are placed on the inner side of stamina tube towards apex close to the stigma. Ovary is 3 carpellary with 2 ovules in each carpel; only one develop in to fruit.

2.5.3 *Pongamia pinnata*

According to Raju and Rao (2006) the karanj inflorescence is a long raceme with 61±8 flowers, which anthese acropetally over a period of 11±□4 days. The flowers are large, mildly fragrant, bisexual and zygomorphic. The calyx is dark purplish-brown and cuplike. The corolla is papilionaceous with two light-purple wing and two white keel petals and one greenish-white standard petal. The standard petal is broad with a light greenish-yellow nectar guide at the centre. The keel petals represent a boat-shaped structure in which the stamens and stigma are embedded.

The stamens are ten, diadelphous with nine stamens united into one bundle and the tenth one in free condition. The bundled stamens form a staminal tube at the base and the filaments become free towards the apex and bear monomorphic, dithecous anthers. All the ten stamens have prominent upward arching. The ovary is semi-inferior with a single carpel having two (rarely one or three) ovules. It has a white style terminated with a small wet stigma.

2.5.3 Number of flowers per inflorescence

Chang-wei *et al*. (2007) selected 30 inflorescences as a sample to observe the floral display of *J. curcas*. The average number of female flowers and male flowers per inflorescence was 8 (2–17) and 184 (88–238) respectively.

Kumar *et al*. (2008) conducted a study on morphological, nutritional and biochemical traits in 27 accessions of *Jatropha curcas*. This study indicated the number of female flowers/inflorescence showed highest variation among the morphological traits studied.

2.6 Reproductive/Floral biology

The basic mechanics of plant reproductive biology is very important in understanding how to maximize the yield and quality of the seed. The inherent biological processes of the flower and its sexual parts are often the first place a seed grower looks to when a particular seed crop is not performing adequately.

2.6.1 Anthesis and anther dehiscence

Jatropha curcas flowers showed the forenoon (800-1200) pattern of anthesis with subsequent pollen release (Bhattacharya *et al*., 2005). Raju and Ezradanam (2002) reported that flowers of *Jatropha curcas* open daily during 0530 – 0630 h. The anthers dehisce an hour later by longitudinal slits. The flowers show protandry by opening male flowers on the first day.

The reproductive biology study of neem was done by Sharma and Khanduri (2007) in Central Himalaya. As a part of this study, the twigs were marked for counting the opened flowers at every 2 h over a day. Maximum anthesis during 1998 and 1999 occurred between 1200 and 1400 h.

Raju and Rao (2006) conducted pollen studies in *Pongamia pinnata* in Eastern Ghats and Vishakapatnam. The time of anthesis and anther dehiscence was noted by observing marked mature buds in the field. Mature buds open during 0700–1000 h with peak anthesis at 0800 h. Unfolding of the standard petal indicates flower opening. All the ten anthers dehisce by longitudinal slits in mature bud stage, approximately 3 h prior to anthesis.

Anther dehiscence occurred at the time of flower opening in *Santalum album* (Bhaskar, 1993). Kulkarni and Muniyamma (1998) reported the average time from bud initiation to complete flower development is 34 days in *Santalum album.*

Raju and Rao (2006) documented time of anthesis during 08.00-11.00 and anther dehiscence by splitting of anther lobes, an hour after anthesis in *Gmelina arboea*. Kumar (2004) reported that anthesis (blooming of flowers in a day) occurred between 07:30 and 08:30 h in *Saraca asoca.* The style and the stamen appeared coiled just after anthesis but quickly open up within a few minutes. The anther dehiscence started at around 09:30 h and achieved its peak at 10:30 h. All the anthers of a flower dehisce simultaneously.

2.6.2 Stigma receptivity

The characteristics of angiosperm stigma was studied in detail by Heslop and Shivanna (1977) including about 1000 species of plants. According to Ashoke Bhattacharya *et al*. (2005) the stigma of *J. curcas* flower becomes receptive 1-2 h. after flower opening. Morphological differentiation of stigma before and during their receptive period was noticed. The stigmas are receptive after the flowers open and remain so for three days (Raju and Ezradanam, 2002).

In pollination study of Karanj by Raju and Rao (2006) tested stigma receptivity with H2O2 according to Dafni (1992). Emission of bubbles from the stigma surface with great speed was taken as strong receptivity, while the slow emission of bubbles as weak receptivity. The stigma attains receptivity one hour after anther dehiscence, but strong receptivity occurs during 0900–1600 h.

In most of the plant species, maximum stigma receptivity occurs at or shortly after anthesis. Garton (2000) stated that stigma become receptive to pollen during maturation of the flower bud in sacred Lotus (*Nelumbo nucifera*).

Sambamurthy and Ramalingam (1954) considered the stickness of the stigmatic surface as the indication of the stigmatic receptivity in jack fruit. They observed that stickness of stigma lasted for 36 hours after protrusion of stigma and intense sticky condition appeared between 8.30 a.m and 9.30 a.m.

The freshly opened dull green flowers and the one-day-old pale pink flowers are receptive to pollination in *Santalum album* (Bhaskar, 1993). Nambiar *et al*. (1978) suggested that in case of protogyny the anthers dehisced at any time, within four days after the stigma become receptive.

2.6.3 Pollen studies

The science of pollen and spores has attracted the attention of research workers. It helps in identifying the disputed varieties or species (Nair and Mehra, 1961). The storage and germination of pollen grain play vital role in assisted pollination and hybridization progamme (Hossain *et al*., 1990).

2.6.3.1 Pollen morphology

Morphological characters of pollen have been used as an important tool in studying the floral biology, interpreting the relationship between plants and origin of plants. Gottsberger (1986) reported that pollen morphology plays an important role in relation to pollinators but it is a field still to be explored.

Raju and Ezradanam (2002) reported the pollen grains are yellow, globular and inaperturate in *Jatropha* flower. Bhattacharya *et al*. (2005) studied the *Jatropha* flower; each flower produced 1617±100 pollen grains with low P:O ratio (539:1). Lakshmi *et al*. (1997) described pollen grain characteristics of *Pongamia pinnata*, suggesting that the grains are small, tricolporate and adhere in clumps. Singh and Misra (1979) studied the characteristics of the pollen of three species of *Zizyphus*. Studies on the pollen morphology of jack were carried out by Prasad and Trivedi (1978).

2.6.3.2 Pollen viability and fertility

The extent of pollen fertility is of vital importance in hybridization work. Zirkle (1937) described the method of mounting pollen grains in acetocarmine. Kaul *et al*. (2005) estimated pollen viability by acetocarmine test in *Withania sominifere* and was found to be 90.5 per cent during peak flowering season. Parameshwar (1973) found that fertility of the pollen grains was found to be 85 per cent in *Flacourtia inermis* as indicated by the acetocarmine staining method.

2.6.4 Pollination studies

2.6.4.1 Mode of pollination

Riabove (1930) had given a most comprehensive survey about the pollination of tree containing about 800 references. He stressed the possible influence of environment on modes of pollination and physiological conditions of plant on fruit set. According to Cruden (1988) *Jatropha podagrica* showed dichogamy with protogyny. Schmutterer (1995) and Singh *et al*. (1995) explained the mode of pollination in *Azadirachta indica* as out crossing and the pollination is performed by insects. Although the flowers are protandrous in neem, selfing has been reported (Gupta *et al*., 1996). Selfing may occur when insects visit close neighbours or different branches of the same tree (Mathew and Das, 1987).

Sandal has an ambivalent reproduction system and can be designated as a "often cross-pollinated" species. Bhaskar (1993) reported that flowers of *Santalum album* are self-incompatible and strictly adapted for cross-pollination by insects.

2.6.4.2 Floral visitors

Pollination is transfer of pollen from male reproductive structure to receptive stigmas. Excluding some parthenocarpic and autogamous species, the

pollination process requires the intervention of a vector to effect pollen transfer. Insects are by far the most significant pollinating agents in tree crop species (Faegri and Piji, 1979).

Pollinator management is an important activity for seed set by quality and quantity. Pollen flow between male and female flowers should occur for fruit and seed set. Seed quality depends mostly on cross-pollination in *J. curcas* (Raju and Ezradanam, 2002). Bhattacharya *et al*. (2005) reported that the insects of Hymenoptera and Coleoptera pay visits with different modes of flowers in *J. curcas*. He also stated that honeybees (*Apis dorsata*, *A. florea* and *A. mellifera*) are effective pollinators. Bees and flies mediate pollen flow between male and female flowers in the same and different individuals in *J. curcas* (Raju and Ezradanam, 2002).

The study on pollination of *Pongamia pinnata* by Raju and Rao (2006) recorded the flower visitors and foraging visits made by bees at each hour. Flower visitors included bees [*Apis dorsata*, *A. cerana*, *A. florea, Trigona iridipennis*, *Ceratina simillima*, *Pithitis binghami*, *Amegilla* sp., *Xylocopa latipes*, *X. pubescens* and *Megachile* sp., wasps (*Sphex* sp., *Vespa* sp., *Ropalidia spatulata, Delta pyriformes*) and thrips (*Thrips hawaiiensis* and *Haplothrips tardus*). All visitors foraged throughout the day with more foraging activity during the forenoon hours, especially during nectar secretion period. The pollen and nectar are good honey bee forage during summer season in *Pongamia pinnata* (Lakshmi *et al*., 1997).

Srivastava (1993) reported the pollination mechanism in the genus *Terminalia* Linn. Five orders of insects viz., Lepidoptera with six of its species, Hymenoptera with six of its species, Hemiptera with two of its species, Coleoptera with two of its species, and Diptera with six of its species were involved in their

pollination. It was also observed that the pollen foraging insects operated between 7.30 and 12.00 hrs in the morning and 15.00 to 17.00 hrs towards evening.

According to Bhaskar (1993) the commonest pollinators in *S. album* include flies and bees, seeking nectar in the cup-like disc Honey bees (*Apis cerana*, *A. dorsata* and *A. florea*) dominated during the early part of flowering.

2.6.5 Fruiting behaviour

2.6.5.1 Fruit set

The term fruit set is used rather loosely in angiosperms and it refers to either the initial or final fruit set. Initial fruit set occurs shortly after anthesis and involves swelling of the ovary. Flowers which do not set fruit may turn yellow and shed from the tree. Final fruit set is the number of fruits that remain on the tree at fruit and seed maturity. Final fruit set is generally lower than the initial fruit set and is due to fruit drop during the developmental period.

Raju and Rao (2005) stated that in *Jatropha curcas*, fruit production starts from second year onwards in cuttings and third year onwards in seed produced plants. Once planted, it produces seed crop for more than 50 years. A plant of about 7 years of age produces about 2-5 Kg seed per year with 30-35% oil content. Fruit set rate is related to the number of female flowers produced by the plant. Natural fruit/seed set rate varies from 37% to 61% (Raju and Ezradanam, 2002). The *Jatropha* plant shows flower-fruit ratio of 10:1 and 50% of female flowers set fruit (Bhattacharya *et al*., 2005).

According to Kun *et al*. (2007) *J. curcas* can bear fruits twice a year, from March-April and from September-October and yield fruits from August-September and from March-April of the following year. In terms of the amount of blossoms and fruits, the first bearing is better and the seeds are more plump.

Pandey and Mandal (2006) observed wide variation for number of fruits per bunch ranging between 6 and 30.

2.6.5.2 Fruit development

Raju and Ezradanam (2002) concluded that ratanjyot fruits mature in 2 to 3 months. Each fruit produces 3 seeds, which are initially green, later yellow and finally brown/black. Early summer season is ideal for fruit/seed collection. Kun *et al.,* (2007) observed fruits ripening in September and October. During this period, the pericarp colour changes from green to yellow. Those with golden yellow pericarp should be collected. Makkar *et al*. (1998) studied four verities of *J. curcas* collected from Nicaragua (Cape Verde and Nicaragua toxic varieties cultivated in Managua), Nigeria (a wild variety from Ife) and Mexico (a wild non-toxic variety collected from Papantla and reported the average fruit weight of Ife-Nigeria variety to be 2.1 g.

For recording fruit setting in *Azadirachta indica*, Sharma and Khanduri (2007) tagged five trees on each site observations were made after 20 and 50 days of pollination. The length and diameter of the fruits were calculated using a vernier calliper. The average weight and size of fruits were calculated. Fruits of *Azadirachta indica* reach maturity when drupes begin to turn pinkish yellow in colour from green and begin to fall to the ground. During this stage the fruit attained maximum fresh weight, dry matter, germination, and minimum time to complete germination (Nayal *et al*., 2002). The neem fruits become brown in colour during August–September and by the end of September, they start dehiscing. Fruit dropping starts more or less along with the leaves, which is completed by the end of November (Sharma and Khanduri, 2007).

The average time taken from bud initiation to complete fruit maturation was 110-140 days in *S. album* (Kulkarni and Muniyamma, 1998). The fruit (pod) of *Pongamia pinnata* takes about one year time for maturation. Each fruit

produces 1-3 seeds; 1 and 2 seeded pods are common in *Pongamia* (Raju and Rao, 2005). Alex (1996) stated that *Garcinia mangostana* L. fruits attained maturity 90 days after fruit set. The endocarp of *Azadirachta* encloses one, sometimes two and rarely three seeds (Schmutterer, 1995 and Singh *et al*., 1995).

2.6.5.3 Fruit drop

Detailed study on the fruit set and fruit development is lacking in *Jatropha*. Some per cent of self-pollinated (geitonogamy) fruits in *J. curcas* drop off prematurely. Cross-pollinated fruits do not drop off and all develop to maturity (Raju and Ezradanam, 2002). Several reports of fruit drop are available in many fruit crops, viz., citrus (Navriyal, 1955; Pollard and Biggs, 1969) and mango (Singh, 1964). Baker and Harris (1957) reported that in the West African species *Parkia capertoniana*, only four to five fruits develop out of the approximately 2000 fertile flowers.

2.7 Seed technological aspects

There is scanty information on the seed biochemical aspects of endangered species, which is important in conservation of the species.

2.6.1 Physico-chemical aspects

2.6.1.1 Physical characters

2.6.1.1.1 Seed germination

The seeds of some species will tolerate only a slight degree of dehydration (Chaitanya and Naithani, 1998) and are called recalcitrant while other categorized as intermediate will survive to far lower water content (Varghese and Naithani, 2000). Germination potential of *Jatropha curcas* seeds from in and around Tamil Nadu and Kerala was assessed by Kumar and Swarnkar (2003). Studies conducted by Joker and Jepsen (2003) revealed that freshly harvested seeds of *J. curcas*

possess dormancy and after ripening is essential for germination. Research on viability of *Jatropha* seeds by Kobilke (1989) showed that a decrease in germination due to storage. Seeds older than 15 months show viability below 50 per cent.

The germination percent and germination capacity in *Azadirachta indica* seeds were studied by Verghese and Naithani (2000). Hundred per cent germination upto 15 days after harvest was recorded. The average germination percentage of *Pongamia pinnata* seeds from different seed sources of Karnataka was 60.40 (Shivanna *et al*., 2007).

The germination test of *Pongamia* seeds conducted in NBPGR, New Delhi showed 44 percent and 68 per cent in control condition and pre-soaked in water respectively (Kumar *et al*., 2007). Nazaraudeen *et al*. (2005) reported that freshly sown seeds of *Artocarpus hirsutus* registered 98 per cent germination and it rapidly lost its viability in storage under open condition. Baghel (2003) reported that seeds of Jack fruit (*Artocarpus heterophyllus* Lam.) showed highest germination percentage and vigour when they were sown just after extraction. Germination capacity and seedling vigour of *Santalum album* has been analyzed by Manonmani and Vanangamudi (2002).

2.6.1.1.2 Seed dimensions

Seed size and weight are important characteristics of plant species, which depend on a variety of factors like seed source, genetic makeup and the environment where it is growing (Cavers and Steel, 1984). Ginwal *et al.,* (2005) studied on physical parameters of *J. curcas* seeds; weight of 100 seeds (range, 2.95-3.91g; mean, 3.49g), seed length (range, 17.47-18.64mm and mean, 18.12mm), seed width (range, 10.83-11.35mm and mean, 11.06mm), seed viability per cent (range,75.25-91.25 and mean, 84.58), seed germination per cent (range, 61.25-85.78 and mean, 74.48). The average seed weight of *J. curcas* varied

from 0.53 to 0.74 g (Makkar *et al*., 1998). *Jatropha* seed length and seed width varied from 16 to 20 mm and 10 to 13 mm respectively (Pandey and Mandal, 2006).

Geethanjali *et al*. (2003) found that 100 seed weight of *J. curcas* of three categories varied from 70.82g in large, 51.08g in medium and 34.85g in small seeds. Similarly, Kumar *et al*. (2003) reported all the seed traits from five locations of *J. curcas* in Tamil Nadu. In another study it was found that the 100 seed weight was highest in ripe fruits than the dry open fruits. The average fruit weight was highest in ripe fruits than unripe fruits.

Singh *et al*. (2008) stated *Jatropha* fruit are 2.5 cm long, ovoid, black and have 2–3 halves. He also stated the weight of 100 seeds is about 63 g. Kaushik *et al*. (2007) observed maximum seed length 17.63mm and minimum 16.00mm. Seed breadth varied from 7.24mm to 8.33mm. Regarding 100 seed weight, maximum was 69.20g and minimum was 49.20g.

Four varieties of *Jatropha curcas* which originated from Nicaragua (Cape Verde and Nicaragua toxic varieties cultivated in Managua), Nigeria (a wild variety from Ife) and Mexico (a wild non-toxic variety collected from Papantla) were studied by Makkar *et al*. (1998). According to this study, the average seed weight was 0.69, 0.86, 0.53 and 0.65g for Cape Verde, Nicaragua, Ife-Nigeria and non-toxic Mexico varieties, respectively. The average seed weight ranged from 0.53 g in Ife-Nigeria to 0.86g in Nicaragua variety, indicating varietal difference.

Shivanna *et al*. (2007) assessed the seed parameters among different seed sources of *Pongamia pinnata* in Karnataka. The average values recorded were, seed length – 7.14mm, seed width – 6.15mm and 100 seed weight – 20.77g. The *Pongamia* seed is elliptical, uniform, compressed, reddish-brown, fairly hard, 2–3 cm long (Kumar *et al*., 2007). Sharma and Khanduri (2007) reported that the neem

seeds were ex-albuminous, about 2.5 cm in diameter, dark brown, smooth and shining.

2.6.1.1.3 Moisture content and density of seed

Optimum moisture content is highly significant for extending viability. Singh (2008) analyzed different physico-chemical parameters of *J. curcas* seeds. According to this the seed moisture content was 4.5 per cent and weight of 100 seeds was 60 g. The moisture content of *Jatropha* seed showed significant variation among the collections from different locations of Tamil Nadu and Kerala that ranged from 6.1 per cent in Walayar seed source to 4.2 per cent in Partipatti seed source (Kumar *et al*., 2003). Analysis of *J. curcas* seed by Sharma (2005) revealed 6.2 per cent moisture content.

Annarao *et al*. (2008) studied seed development in *Jatropha curcas*. Seeds were collected at various stages of development starting from one week after fertilization and these were classified into seven. This study reported moisture content of the seeds ranged from 8.8 to 90.3%; the lowest in mature seeds in stage VII and highest in stage I. Openshaw (2000) reported 5 per cent moisture content of whole nut of *J. curcas*.

Akintayo (2004) reported content in *Parkia biglobbossa* (PKBS) and *Jatropha curcas* (JTC) seeds in Ekiti state, Nigeria. Study showed 10.18 and 5.54 per cent moisture in PKBS and JTC respectively. Gandhi *et al*. (1995) reported 4.3 per cent moisture in *Jatropha* kernel by studying the proximate composition in Andheri (East), Bombay.

Mangaraj and Singh (2006) and Sirisomboon *et al*. (2007) found out some physical and mechanical properties of *Jathropha* at a particular moisture content. The post-harvest physical and mechanical properties of *Jatropha curcas*. fruits, nuts and kernels were investigated and reported by Sirisomboon *et al*. (2007).

According to the study, the solid densities of fruits, nuts and kernels were 0.95, 1.04 and 1.02 g/cc respectively.

Karanj seeds extracted from fruits showed 14.32% moisture content on fresh-weight basis (Kumar *et al*., 2007). The seed storage behaviour, germinability and moisture content of mahua (*Madhuca indica*) was studied by Verghese *et al*. (2002). The mature seeds, which were shed at relatively high moisture content (53%), exhibited 100% viability.

The average seed density in *Saraca asoca* was 1.15 g/cc, with a range of 1.1 to 1.2 g/cc (Kumar, 2004).

2.6.1.2 Chemical characters

Chemical analysis of *J. curcas* oil and its potential as a substitute for diesel engine fuel has been performed by number of workers (Sharma, 1985; Bhatia, 1986; Mathur and Das, 1986; Nasir *et al*.,1988 and Ouedraogo *et al*., 1991).

2.7.1.2.1 Proteins and carbohydrates

Zippel and Deters (2006) determined protein content (10%) of the crude extract by Bradford (1976) Test. Gubitz *et al*. (1999) studied the chemical composition of the *Jatropha* seed based on dry weight. He reported 22.2 to 27.2 per cent and 4.3 to 4.5 percent protein from seed kernel and shell respectively.

A study on physico-chemical parameters of *J. curcas* seeds by Singh (2008) showed 16.59 per cent carbohydrate and 19.45 per cent crude protein. Makkar *et al*. (1998) stated that the seed comprised 27–30 per cent of crude protein. Analysis of seed exhibits 18 per cent protein and 17 per cent carbohydrate (Sharma, 2005). Gandhi *et al*. (1995) recorded 23.3 per cent protein and 12.1 per cent carbohydrate in *Jatropha* seed kernel.

Four provenances of *J. curcas* from different agro-climatic regions of Mexico, that differed in morphological characteristics were studied by Martínez-Herrera *et al*. (2006). The seed kernels were rich in crude protein (31–34.5%) and lipid (55–58%). The contents of starch and total soluble sugars were below 6 per cent. Akintayo (2004) analyzed *Parkia biglobbossa* (PKBS) and *Jatropha curcas* (JTC) seeds for their proximate analysis in Ekiti state, Nigeria. Proximate analysis revealed that the percentage crude protein and carbohydrates in PKBS were 32.40 and 13.20 per cent, and 24.60 and 7.99 per cent in JTC.

Ogbobe and Akano (1993) assessed the physico-chemical properties of the seed and seed oil of *Jatropha gossipifolia*. The seed contained 35.8 per cent crude oil, 13.40 per cent protein, and 30.32% carbohydrate. Wafaa *et al*. (2007) assessed the neem seed for its chemical composition in Dubai (United Arab Emirates). The results of protein and carbohydrate measured in grams per 100 g dry weight were 47.2 per cent and 9.4 per cent respectively. The physico chemical analysis of Simaruba oil seed (water soaked) revealed 49.5 per cent crude protein (Behura *et al*., 2008).

Yusuf *et al*., 2007 studied physical parameters and nutrient contents of the whole seeds and seed nuts of *Caesalpinia pulcherrima.* He reported that crude protein was between 42.97-48.08 per cent and carbohydrate was found to be 18.30-39.10 per cent.

2.6.1.2.2 Fatty acids

Jatropha seeds contain 30-50 per cent semi-drying oil of pale yellow colour with acrid taste. The oil contains saturated fatty acids and unsaturated fatty acids (Singh, 2008). A study on phenology, oil content, lipid profile and concentration

of sterols by Annarao *et al*. (2008) revealed the presence of free fatty acids (FFA) in *Jatropha curcas* seeds.

Fatty acid composition of oil samples of four species of *Jatropha* (*J. curcas*, *J. glandulifera*, *J. gossififolia* and *J. multifeda*) were determined by Banerji *et al*. (1985). All the oil samples were rich in fatty acid content and no correlation between the energy values and fatty acid composition could be obtained. Haas and Mittelbach (2000) recorded 1.9 per cent free fatty acid from *Jatropha* seed oil. Seed contains about 40–42 per cent husk/hull and 58–60 per cent kernels and the kernels have about 50 per cent oil (Singh *et al*., 2008).

Berchmans and Hirata (2008) studied on biodiesel production from crude *Jatropha curcas* seed oil with a high content of free fatty acids. He reported crude seed oil was having 14.9 per cent FFA (Free Fatty Acids). Foidl *et al*. (1996) analyzed the seeds of two *Jatropha* varieties, namely Caboverde and Nicaragua, in Managua, Nicaragua. They found 0.29–0.49 and 0.60-1.27 per cent of free fatty acids in Caboverde and Nicaragua respectively.

Gupta *et al*. (2008) studied on free fatty acid composition of *Jatropha curcas* oil and Karanja (*Pongamia pinnata*) oil. They reported the increase in viscosity, free fatty acid content, and density of oil during storage. Ghadage and Raheman (2005) reported mahua oil (*Madhuca indica*) having high free fatty acids (19% FFA). Naik *et al*. (2008) stated the karanj seed oil containing FFA (free fatty acids) up to 20 per cent.

Materials and Methods

MATERIAL AND METHODS

The present series of investigations were carried out at the Department of Forest Management and Utilization, College of Forestry, Vellanikkara, Thrissur, Kerala during the period 2006 to 2008 with the objectives of understanding the reproductive biology and seed technological aspects of a potential tree-born-oil seed plant, *Jatropha curcas* Linn.

3.1 Study site

The study site lies between 10º 32´ N and 76º 26´ N longitude at an altitude of 22-25m above MSL. The climate is warm humid with an average annual rainfall of 3000 mm, most of which is received between June to September. The mean maximum temperature is 28.6ºC to 36.5ºC and the minimum temperature is 21.6ºC (July) to 25.6ºC (April). The soil is lateritic in origin.

3.2 Phenology

Ten plants were selected and monthly observations were made on time of flowering, fruiting, leaf shedding and flushing. The duration of each event from February 2007 to December 2007 was also recorded. A View of the experimental site is depicted in Plate 1.

3.3 Floral biology

3.3.1 Inflorescence characters

The inflorescence was studied for its type, length and breadth, number of buds and flowers, and number of fruits. Time of flowering was studied by

Plate 1. A View of the study site at the College of Forestry, Vellanikkara

observing 10 plants selected randomly from the population. Observations on number of inflorescence per plant and number of flowers per inflorescence were recorded.

3.3.2 Time taken for inflorescence development

In order to study the time taken for full development of inflorescence from visual stage of formation, ten young flowering shoots from five different plants was tagged soon after appearance of flower bud in the leaf axil. Photographs of different stages of inflorescence development and succession of blooming were taken.

3.3.3 Time taken for the full bloom of inflorescence

Time taken for the full bloom of inflorescence from opening of first flower to the last flower in a inflorescence were recorded. Observation was taken from 10 inflorescences and the average was computed.

3.3.4 Flower bud development

The shoots in each plant were tagged for extension growth studies. The shoots were periodically observed during the flowering season to find out the exact time of visual emergence of flower buds. Progressive stages of flower bud development was studied by labeling and closely watching flower buds randomly selected on each plant.

Buds were tagged soon after their emergence. Observations were made on the time duration between emergence of flower bud to flower opening, bud to flower ratio and bud to fruit ratio.

3.3.5 Floral morphology

Five fresh flower buds and flowers were collected. Hand sections (both L.S and T.S) were taken and examined under occular microscope and description of morphological features like size, colour, and number of floral parts; sepals, petals, androecium and gynoecium were recorded. Floral formula and floral diagrams were drawn.

Five inflorescences were marked on different plants, and diameter of lower, length of style and diameter of stigma were measured. The number of hermaphrodite, pistilate and staminate flowers in a inflorescences were separately counted and recorded. The percentage of these flowers to the total in an inflorescence was also worked out.

3.3.6 Anthesis

With the objective of understanding the exact time of flower opening, 10 mature flower buds were marked and the time at which the buds started to split, and the time at which the petals unfolded completely were noted at 1 hour interval. The observations were repeated over a period of 4 days.

3.3.7 Anther dehiscence

The inflorescences tagged for determining the time of anthesis were utilized for ascertaining the time of anther dehiscence. Anther sacs were examined at every 15 minutes interval to arrive at the time of anther dehiscence.

3.3.8 Stigma receptivity

To determine the exact time of stigma receptivity, the flowers tagged to study the anthesis were observed through peroxidase test. In the peroxidase or enzyme activity test, the stigma receptivity was tested with H_2O_2 (Dafni, 1992). The excised stigmas were plunged into freshly prepared, H_2O_2 solution. The bubbling at stigmatic surface or turning brown was taken as an indication of receptive stigma.

3.3.9 Pollen studies

Anther sacs collected from the fully opened flowers just prior to the time of anther dehiscence were allowed to dehisce in water taken in a petri dish. The pollen suspension prepared by gentle crushing of such anthers was utilized to study pollen morphology, viability and fertility.

3.3.9.1 Pollen morphology

A drop of pollen suspension was transferred to acetocarmine solution kept on a clean glass slide. After covering with a clean cover slip, the slides were kept as such for 10 minutes for the pollen grains to get stained and were examined under a microscope.

3.3.9.2 Pollen viability and fertility

Staining technique to study the fertility of pollen grains was adopted from Zirkle (1937). Fertility of the pollen grain was assessed based on the stainability and shape. Pollen grains normally shaped and stained in acetocarmine were treated as viable and fertile whereas unstained and irregular shaped were regarded as non-viable and sterile. Pollen fertility was expressed in percentage.

3.3.10 Mode of pollination

To ascertain the precise mode of pollination, fruit set was observed by tagging 10 inflorescences from ten plants. Observations on number of buds initiated and fruit set was recorded.

3.3.10.1 Open/natural pollination

In order to know the extent of open pollination under natural conditions (cross pollination), 10 inflorescences were selected (one inflorescence in each plant) and tagged. These were later examined for fruit set and percentage was calculated in each mode of pollination.

3.3.10.2 Self pollination

Ten inflorescences (of matured flower buds), one in each plant, were covered with butter paper to prevent pollen contamination from outside. The covers were removed after fruit set and percentage of fruit set was determined. Based on number of fruit set, the percentage mode of pollination was calculated.

3.3.10.3 Wind pollination

Ten inflorescences (of matured flower buds), one in each plant, were covered with nylon mesh to prevent pollen from insect pollinators. The mesh was removed after fruit set and percentage of fruit set was determined.

3.3.10.4 Flower pollinators

To study the role of insects in natural pollination of *Jatropha*, close observations were made at 1 hour interval to see if any insects visited the flowers. This was repeated for 3 days during peak flowering period. The insects visiting the flowers were trapped and identified.

3.3.12 Fruiting behaviour

3.3.11.1 Fruit set

The extent of fruit set was determined in both open pollination as well as self pollination. Ten inflorescences (one in each plant) were tagged at the bud initiation stage and observed to set fruit. The percentage was worked out by counting the number of buds set into fruits. The time duration between flowering and fruiting was also determined.

3.3.11.2 Fruit development

In order to study the developmental changes with respect to physical parameters such as total weight, total number and weight of seeds, fruits were picked at different maturity phases such as greenish yellow fruits, yellow fruits, brown and black fruits.

3.3.11.2.1 Fruit weight

The weight of the fruits were determined in electronic balance and expressed in grams.

3.3.11.2.2 Fruit size

Length and diameter of individual fruit was measured at different maturity stage using high precision Digital Caliper and expressed in centimeters.

3.3.11.3 Fruit drop

The percentage of fruit drop was calculated by taking the ratio of retained fruits (at the stage of fruits turned black colour) to the total number of fruit set.

3.4 Seed technological aspects

3.4.1Physical characters

The following characters were determined from the seeds collected at the different maturity stages viz., greenish yellow fruits, yellow fruits, brown fruits and black fruits.

3.4.1.1 Seed germination

To understand the germination behaviour, *Jatropha* fruits were harvested at different maturity level viz., greenish yellow, yellow, brown and black coloured fruits. The seeds were allowed to germinate in germination tray in poly house, without giving any pretreatment. Ten seeds together constituted one replication and there were three replications in each maturity stage.

Number of seeds germinated was monitored everyday till no further germination is noticed. The data obtained were used to find the maturity stage of seeds, germination percentage and germination capacity.

$$\text{Germination percentage} = \frac{\text{Total number of seeds germinated}}{\text{Total number of seed used}} \times 100$$

The stage in which largest germination percentage was obtained was designated as the matured seed (suggested to harvest).

3.4.1.2 Seed dimension

Seeds were drawn randomly and measured for their maximum length, width and thickness in millimeter up to two decimal places using precision Digital Caliper. Seeds were air-dried properly before storing in container at ambient room temperature.

3.4.1.2.1 Individual seed characters

Ten seeds were randomly selected from the fruits harvested at different developmental stages and the following characters were determined individual seed wise in order to find out the relationship among the characters.

3.4.1.2.1.1 Seed length

The length of the seed from the base to tip was measured using digital caliper and the average was expressed in mm.

3.4.1.2.1.2 Seed diameter

The diameter at the middle of seed was measured using digital caliper and the average was expressed in mm.

3.4.1.2.2 Individual Seed weight and Hundred seed weight

The weight of single seed was measured and the average was expressed in grams. The hundred seed weight was also determined and expressed in grams.

3.4.1.3 Seed moisture content and seed density

The moisture content of seed was determined on fresh weight basis. After taking initial weight of 1g, 2g, 3g etc., the seeds were oven dried at temperature of 60ºC and 105ºC until constant weight was achieved, and dry weight was recorded. The percentage of moisture content was worked out by using the formula,

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

The density of the seed was measured on volume basis using water displacement method. The following formula was adopted to calculate the seed density.

$$\text{Seed density} = \frac{\text{Weight of seed (g)}}{\text{Volume of water displaced by the seed (ml)}}$$

3.4.2 Chemical aspects

The seeds extracted from yellow coloured fruits were subjected to chemical analysis and composition of protein, carbohydrate and fatty acid was determined. The chemical analysis was carried out on dry weight basis. The seeds were stored at ambient room temperature after extraction. Both kernel and shells were separately analyzed.

3.4.2.1 Protein determination

The seed protein was determined according to Bradford (1976) method. One gram of sample was used in both the cases (kernel and shell) in each replication. The standard was prepared according to the procedure. After the samples were centrifuged, Bradford reagent was added to both sample tubes as well as standards and also to tubes kept for control. The readings were taken in Genesis Thermo spectrometer at 595ŋm. The amount of protein was expressed in mg. Later it was converted into percentage.

3.4.2.2 Carbohydrate determination

Since the experimental material was the seed, the total carbohydrate was determined. The carbohydrate content of the solution was determined by phenol sulphuric acid method as suggested by Sadasivam and Manickam (1996).

3.4.2.3 Fatty acid determination

The seed sample was ground into a coarse powder. The crude oil content of the seed material was determined by Soxhlet method. The percentage of the oil was calculated on the basis of the weight of seed sample. Untreated *J. curcas* seed oil was used as starting material. One ml of oil was used to determine the free fatty acid present in the seed sample.

Results

RESULTS

The results of the present investigation titled "Floral biology and seed technological aspects of *Jatropha curcas* Linn." are presented in this chapter.

4.1 Phenology

The important periodical events such as flowering, fruiting, leaf shedding and leaf flushing were observed to occur two times during the one year study period. The timing of different phenological events and their duration is given in the Table 1.

Table 1. Phenology of *Jatropha curcas*

First season			**Second season**	
Periodical event	**Period**	**Mean No. of days**	**Period**	**Mean No. of days**
Leaf shedding	Jan 2nd week-Mar 2nd week	53.5	May 3rd week-July 4th week	36.1
Leaf flushing	Mar 1st week-Apr 1st week	21.8	Aug 1st week-3rd week	19.1
Flowering	Mar 2nd week-May 3rd week	61.5	Aug 2nd week-Oct 3rd week	64
Fruiting	May 4th week-Jul 1st week	42.3	Oct 2nd week-Nov 3rd week	20.8

First season: First leaf shedding to first fruiting in 2007; Second season: Next leaf shedding to next fruiting in 2007

4.2 Floral biology

4.2.1 Inflorescence characters

The inflorescence is racemose with dichasial cyme pattern. The average number of inflorescence per plant is 12.90 ± 1.13. Flowers are unisexual, and male and female flowers are produced in the same inflorescence. Normally, the inflorescence produces a central female flower surrounded by a group of male flowers.

The inflorescence is having two tiers, large tier and small tier. The average length and spread of the large tier were recorded as 7.62 ± 0.84 cm and 6.37 ± 0.55 cm and 6.10 ± 0.99 cm and 4.35 ± 0.36 cm in small tier respectively.

On an average, an inflorescence took 18.9 ± 0.67 days for its development from visual stage of initiation. Average time taken for the full bloom of inflorescence was 14.2 ± 0.75 days. The average number of male flowers and female flowers per inflorescence were 136.4 ± 10.82 and 8 ± 0.71 respectively. The average male to female flower ratio was 17:3 ± 1.37.

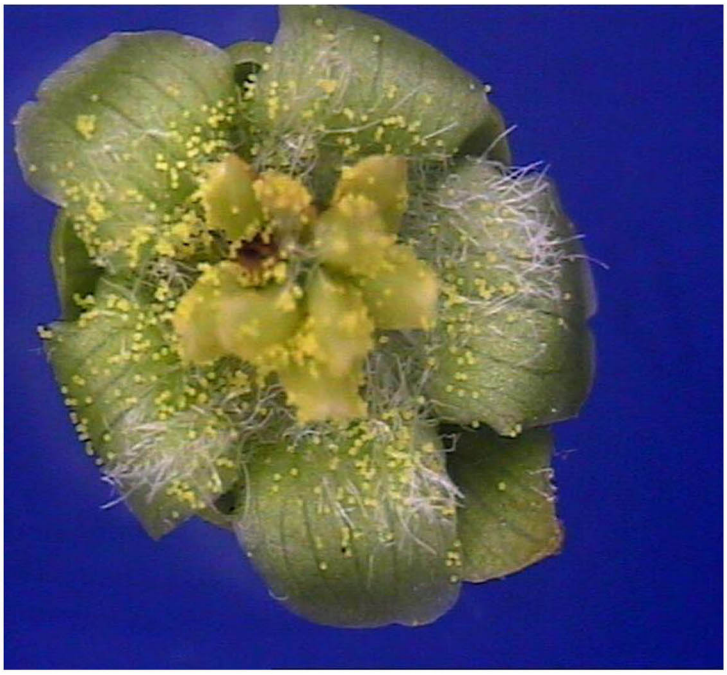
4.2.2 Floral morphology

The male flower is greenish white, odourless and salvar shaped with an average length and spread of 6.95 ± 0.19 mm and 5.54 ± 0.23 mm respectively. The flower is actinomorphic and incomplete. The sepals and petals are five (pentamerous) and free. The sepals are arranged in imbricate aestivation. The petals are valvate and connitent at the flower base forming a short tube.

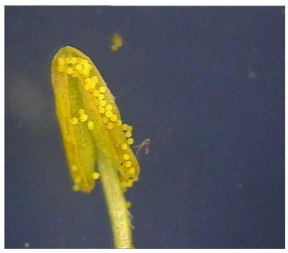
Stamens are ten, diadelphous, arranged in two tiers of five each. The outer tier is free, while the inner tier is united. The average length of stamen was 5.07 ± 0.24 mm. The anthers are yellow, dithecous and dorsifixed. The pollen grains are yellow, globular and inaperturate. The floral base contains nectar in trace amount.

Plate 2. Male and Female flowers of *Jatropha curcas*

Male Flower



L.S

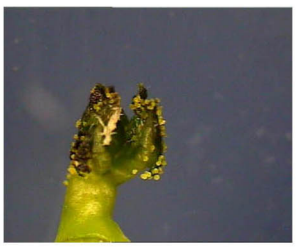


Stamen

Female Flower

L.S

Ovary



Stigma

Female flower is quite similar to the male flower in shape, colour and slightly fragrant, but is relatively larger showing a length and spread of 7.25 ± 0.19 mm and 6.02 ± 0.28 mm respectively. Sepals are free and in imbricate aestivation. The petals are valvate, forming a small tube at the flower base. The styles and stigmas are both three and free. The average length of style was 6.46 ± 0.16 mm. The stigmas are green, darker than petals and are bifid. The ovary has three carpels. The floral base is villose, and contains five elliptical glands under the ovary. The villose flower base secretes nectar in trace amount. Plate 2 depicts the male and female flowers and their parts.

4.2.3 Anthesis

The timing of flower opening is presented in the Table 2. Anthesis started from 06.50 am and lasted up to 11.50 am. The mean time of flower opening was 09.14 ± 0.42 am. Maximum number of flowers opened between 08.30 am and 11.00 am.

4.2.4 Anther dehiscence

The same flowers used for anthesis were observed for anther dehiscence. Anther dehiscence was noticed through longitudinal slits. Anthers dehisced at the mean time of 1.28 ± 0.09 hr (0.88 minutes) after flower opening (anthesis). Anther dehiscence started from 07.55 am to 12.45 pm and maximum flowers dehisced during 9.30 am to 11.30 am.

4.2.5 Stigma receptivity

Stigma receptivity was tested with H_2O_2 as per Dafni (1992) test. The time at which stigma become receptive and also time period between anthesis and stigma receptivity is given in the Table 2. Stigma attained receptivity between 01.20 pm to 2.25 pm hours and remained receptive for 2-3 days. On an average, stigma becomes receptive 2.1 ± 0.12 hr after anthesis.

Table 2. Time of anthesis, anther dehiscence and stigma receptivity

Sl. No.	Anthesis	Anther dehiscence	Time taken after anthesis (hrs)	Stigma receptivity	Time taken after anthesis (hrs)
1	08.35 am	09.20 am	0.45	10.05 am	1.30
2	11.50 am	12.45 pm	0.55	01.10 pm	1.20
3	06.50 am	07.55 am	1.05	08.30 am	1.40
4	09.55 am	10.50 am	0.55	11.25 am	1.30
5	09.20 am	10.35 am	1.05	11.00 am	1.40
6	08.40 am	09.50 am	1.10	10.45 am	2.25
7	10.25 am	11.20 am	0.55	12.10 pm	1.45
8	10.10 am	11.30 am	1.20	12.05 pm	1.55
9	09.15 am	10.25 am	1.10	11.30 am	2.15
10	08.40 am	10.00 am	01.20	10.50 am	02.10
Mean ± SE	09.14 ± 0.429	10.23 ± 0.42	0.88 ± 0.098	09.18 ± 1.027	2.1 ± 0.125

4.2.6 Pollen morphology and fertility

The pollen grains are yellow in colour and globular or spheroidal in shape. The estimated average number of pollen grains per flower was found to be 1601 ± 70 with 91.06 ± 2.42 per cent fertility.

4.2.7 Mode of pollination

Earlier studies by Bhattacharya *et al*. (2005) showed that the mode of pollination in *Jatropha curcas* is out-crossing. In the present study the inflorescence were observed for fruit set per cent in different modes of pollination

viz., cross pollination, self pollination and wind pollination. The average number and percentage of fruits produced in each mode of pollination is presented in the Table 3. In open pollination, the percentage of fruit set was 4.95 (highest among different modes) in relation to total number of flower buds established. Where as the percentage of fruit set in self pollination and wind pollination was 3.7 and 3.28 respectively. The pollen transfer through wind was noticed by covering inflorescence with nylon mesh.

Table 3. Number and per cent of fruit set and fruit drop per cent in different modes of pollination

Treatment	**No. of buds**	**No. of fruits**	**Fruit (%)**	**Fruit no.@ maturity**	**Fruit maturity (%)**	**Fruit drop (%)**
Cross pollination	167.1	8.2	4.95	6.7	85.96	14.04
Self pollination	165.9	6.2	3.70	5.3	81.62	18.38
Wind pollination	145.1	4.8	3.28	3.5	73.12	26.88
	F Test	*	*	*	*	*
	CD	2.41	1.21	2.26	9.23	9.23

*Significant at 5% level

4.2.7.1 Pollinators

The flowers exhibited both entomophilous way of pollination and wind pollination. The insects associated with pollination of *Jatropha* flowers and their per cent of visits are given in Table 4. Honeybees (*Apis indica* Fabr., *A. dorsata* Fabr., and *A. florae* Fabr.) were observed as the predominant insect pollinators.

The bees mentioned above were found to move between flowers, fast, spending a small amount of time in search of more floral rewards. In the pollination of *Jatropha curcas*, *Apis indica* alone accounted 27 per cent.

Table 4. Number and frequency of insect visits in *Jatropha* flower

Sl. No.	**Floral visitors**	**Frequency (5min)**	**Per cent**	**Foraging type**
1	*Apis indica*	9	32	P, N
2	*A. dorsata*	4	14	P, N
3	*A. florae*	6	21	P, N
4	*Vespa sp*	3	11	P
5	*Sphex sp.*	2	7	P
6	*Thrips sp.*	2	7	P, N
7	*Pithitis binghami*	1	4	P
8	*Ceratina simillima*	1	4	P

P: Pollen, N: Nectar

The bees when they visited a flower, moved towards the location of the anthers and stigma. In doing so, they invariably contacted the stigma effecting pollination. Among bees, only long-tongued ones such as *Apis dorsata*, and *A. indica,* are found to have access to nectar. Wasps (*Sphex* sp. and *Vespa* sp.) also caused similar effect in flowers but, their visits were occasional. Thrips sp. being very small, moved inside the flowers and have easy access to both nectar and pollen.

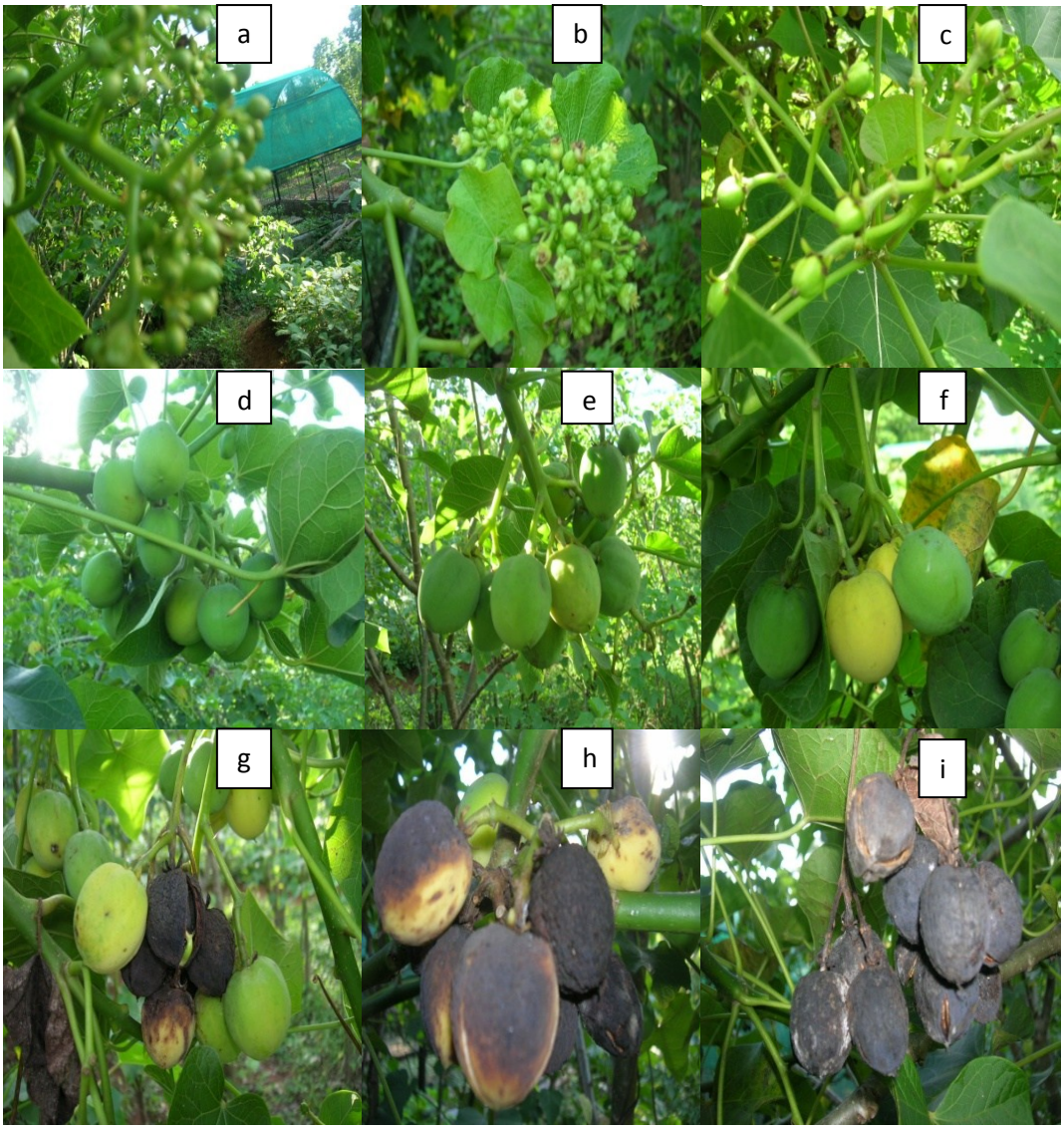


Plate 3. Developmental stages from bud to fruit. a-Matured buds, b-Flower bloomed, c-Initial fruit set, d-Green fruits, e-Greenish yellow, f-Yellow fruits with Green fruits, g-Yellow fruits with black fruits, h-Brown fruits, i-Black fruits.

4.2.8 Fruiting behavior

4.2.8.1 Fruit set

The average number and percentage of fruit set in different modes of pollination is presented in Table 3. In general, the average number of fruits produced was 6.4 giving 3.99 per cent to the total number of flower buds produced. The average number of days taken from flower initiation to fruit set was 13.5.

4.2.8.2 Fruit development

The average number of days between fruit set and different fruit maturity stage is given in Table 5. The initial fruit colour of *J. curcas* is green. It was observed that as fruit matures its colour changed. The average time taken from fruit set to greenish yellow coloured fruit was 14.9 days. The average number of days required to change colour from greenish yellow to yellow was 4.6, whereas 3.8 days taken to change from yellow to brown and 4.5 days for brown to black. On an average, black coloured fruits started to drop after 6.1 days. It was observed that in total, the average number of days taken from fruit set to fruit drop was 33.9. Different stages of flower and fruit development on plant is shown in the Plate 3.

4.2.8.2.1 Fruit size

The fruit showed variation in its dimension at different maturity level. The average maximum length (33.23 mm) and diameter (29.17 mm) were recorded in greenish yellow fruit followed by yellow fruit with 31.97 mm length and 28.47 mm diameter. The least length (28.54 mm) and diameter (25.8 mm) were seen in black fruit (Table 6).

Table 5. Time duration between mature flower bud to fruit set and different fruit development stages

Inflorescence	No. of days b/w mature bud to fruit set	Fruit set-greenish yellow (days)	Greenish yellow-Yellow (days)	Yellow-Brown (days)	Brown-Black (days)	Black-Fruit drop (days)	Fruit set-fruit drop (days)
1	12	14	4	3	4	7	32
2	12	16	3	4	5	5	33
3	13	12	3	3	4	7	29
4	12	14	4	5	3	6	32
5	13	16	5	4	5	8	38
6	15	15	5	2	6	5	33
7	15	18	4	5	3	6	36
8	16	13	6	4	4	4	31
9	15	15	7	3	6	6	37
10	12	16	5	5	5	7	38
Mean±SE	13.5±0.47	14.9±0.51	4.6±0.37	3.8±0.32	4.5±0.32	6.1±0.36	33.9

4.2.8.2.2 Fruit weight

The average seed dimensions and F/S ratio of *J. curcas* is given in Table 6. Maximum fruit weight of 15.9 g was found in yellow coloured fruits and least (12.47 g) in black coloured fruits. Highest (6.86) and lowest (4.32) fruit/seed ratio was seen in brown and green coloured fruits respectively.

Table 6. Fruit characteristics at different maturity level

Treatment	**Length (cm)**	**Diameter (cm)**	**Fruit wt. (g)**	**Seed wt. (g)**	**F/S ratio**
Greenish yellow coloured fruits	33.23	29.17	14.78	3.48	4.32
Yellow coloured fruits	31.97	28.47	15.09	2.36	6.49
Brown coloured fruits	29.89	27.33	14.75	2.16	6.86
Black coloured fruits	28.54	25.8	12.47	1.92	6.55
F-test	*	*	*	*	*
CD	5.407	3.802	3.126	1.784	3.01

*Significant at 1% level

4.2.8.3 Fruit drop

The observation on flower drop in inflorescence showed 94.01 per cent. So, only 3.99 per cent of flowers set in to fruits. Of which, 19.76 per cent of fruit drop was noticed and per cent of fruits attaining maturity was 80.23.

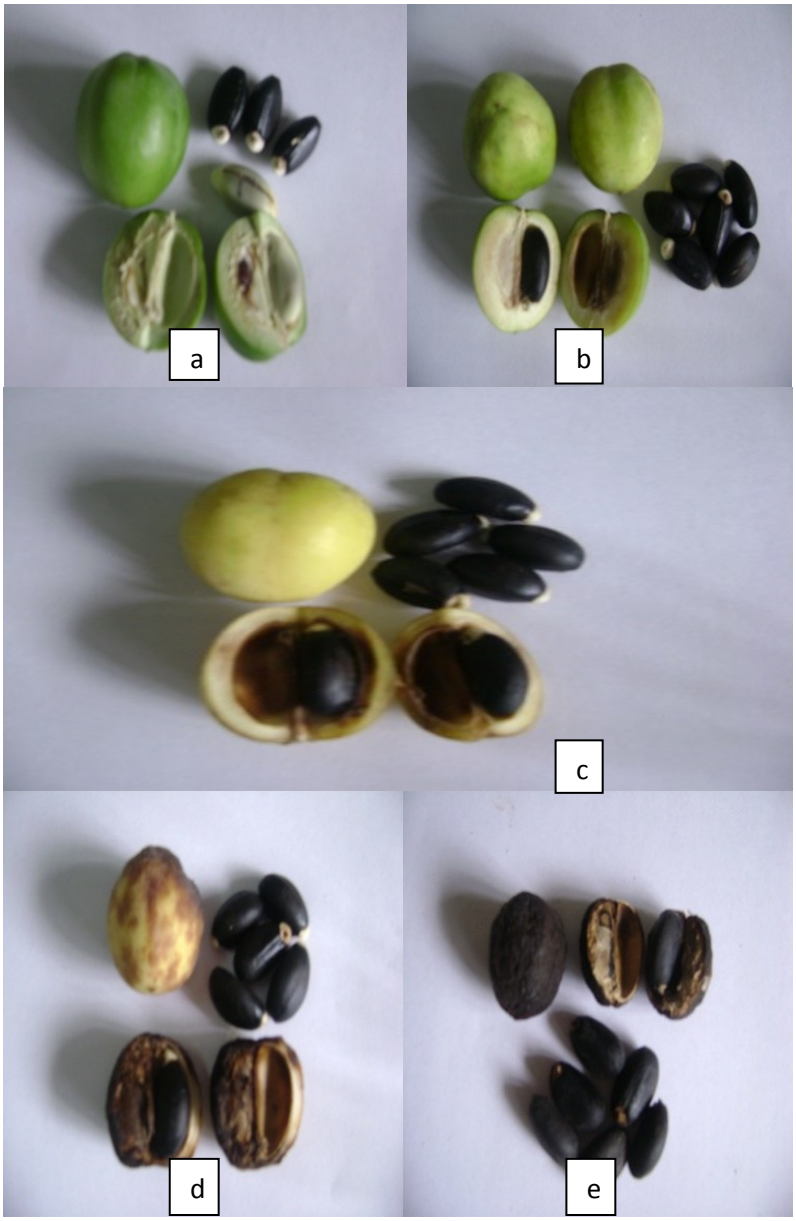


Plate 4. Fruits and seeds at different maturity level. a – Full sized green fruits, b – Greenish yellow, c – Yellow fruits, d – Brown fruits, e – Black fruits.

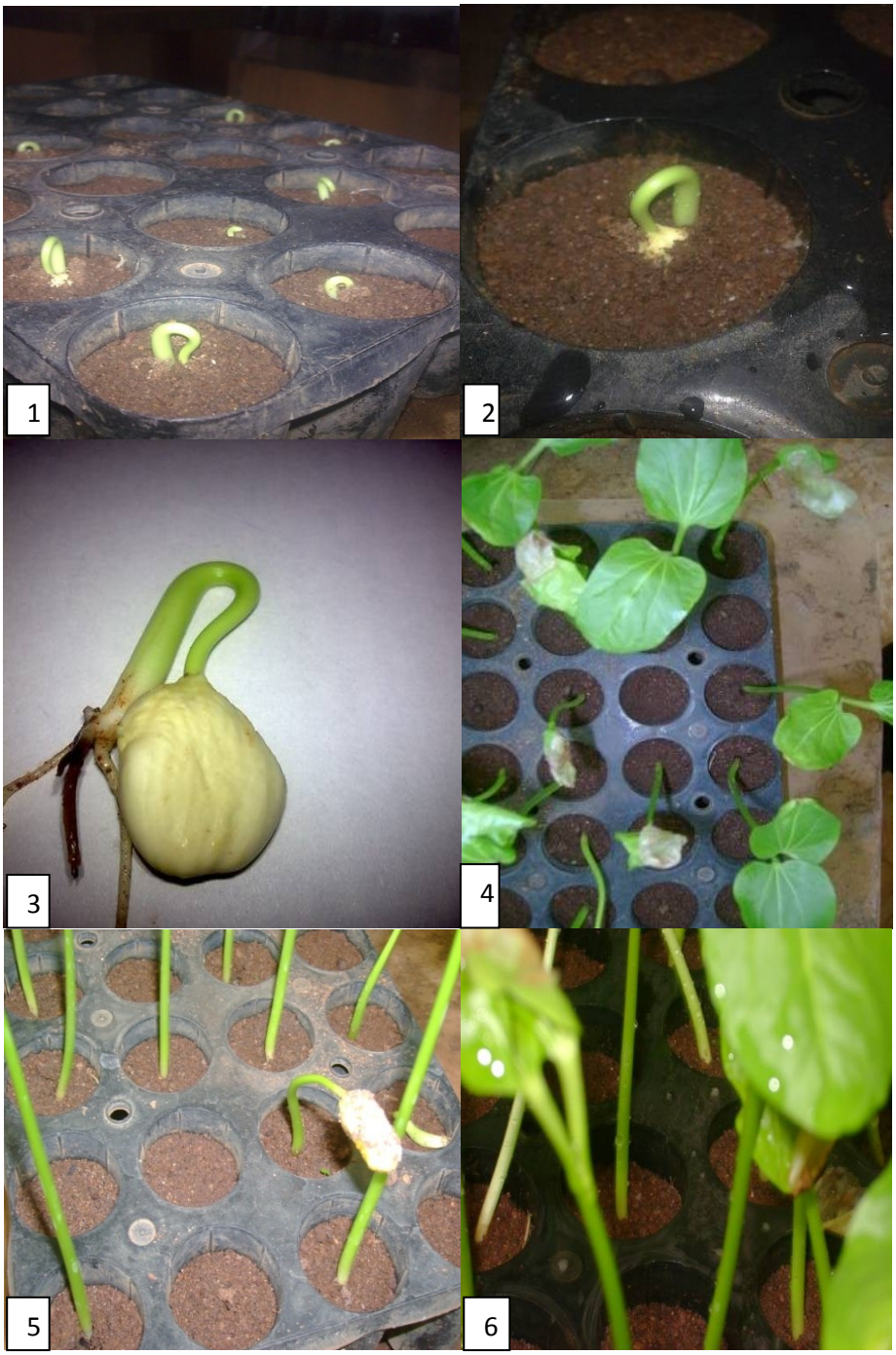


Plate 5. Germination stages of *Jatropha curcas* seed: 1-Germinated seeds in tray, 2-Germinated seed with plumule in tray, 3-Seed with its plumule and radical, 4,5,6-*Jatropha curcas* seedlings in germination tray.

4.3 Seed technological aspects

4.3.1 Physical characters

4.3.1.1 Seed germination studies

The seeds of fruits harvested at four different maturity stages namely, greenish yellow coloured fruits, yellow coloured fruits, brown coloured fruits and black coloured fruits were kept for germination in germination trays kept in poly house. Hundred per cent germination was achieved in the seeds collected from yellow coloured fruits, followed by brown coloured fruits (96.67%). The least germination percentage (80%) was obtained from seeds of black fruits (Table 7). Plate 4 show fruits and seeds at different maturity level and Plate 5 depicts germination of seed and its development.

Table 7. Germination percent and germination capacity of Jatropha curcas seed at different maturity level

Maturity level	**Avg. no. of seeds germinated**	**Germination per cent**	**No. of days to complete germination**
Greenish yellow coloured fruits	9.33	93.33	7.66
Yellow coloured fruits	10.00	100.00	7.66
Brown coloured fruits	9.66	96.67	8.33
Black coloured fruits	8.00	80.00	7.00
F Test	*	*	*
CD	2.147	12.397	0.865

*Significant at 5% level

The seeds extracted from brown and black coloured fruits started to germinate two days after sowing, whereas in case of seed extracted from greenish

yellow and yellow coloured fruits germinated three days after sowing (Table 8). Significant difference was found with respect to germination initiation and completion in different maturity level.

Table 8. Number of seeds germinated every day in different maturity stages

Days	**Greenish yellow coloured fruit (%)**	**Yellow coloured fruits (%)**	**Brown coloured fruits (%)**	**Black coloured fruits (%)**
1st day	0	0	0	0
2nd day	0	0	0	0
3rd day	0	0	06.66	06.66
4th day	10.00	10.00	16.66	20.00
5th day	23.33	20.00	33.33	23.33
6th day	33.33	23.33	16.66	06.66
7th day	26.66	36.66	06.66	0
8th day	06.66	10.00	10.00	0
9th day	0	0	03.33	03.33
F Test	*	*	*	*
CD	18.708	18.559	14.989	12.692

*Significant at 5% level

4.3.1.2 Seed dimension

The average seed measurements at different maturity level varied significantly and are given in Table 9. The maximum seed length (21.54 mm) and diameter (10.71 mm) were recorded in greenish yellow coloured fruits, whereas these dimensions were minimum in black coloured fruits. Average single seed weight (1.376 g) and hundred seed weight (97.45 g) were found highest in

greenish yellow coloured fruits and lowest single seed weight (0.62 g) and hundred seed weight (78.37 g) were recorded in black coloured fruits.

Table 9. Seed dimensions at different maturity level

Maturity level	**Length(mm)**	**Diameter(mm)**	**Single seed wt. (g)**	**100 seed wt. (g)**
Greenish yellow coloured fruits	21.54	10.71	1.37	97.45
Yellow coloured fruits	18.43	9.16	1.02	90.64
Brown coloured fruits	16.99	8.57	0.87	86.76
Black coloured fruits	15.99	8.12	0.62	78.37
F Test	*	*	*	*
CD	4.416	2.059	0.639	59.882

*Significant at 1% level

4.3.1.3 Seed moisture content and seed density

The moisture content and density were determined for the seeds extracted from yellow coloured fruits on fresh weight basis. The average moisture content and density of seed were noted as 13.39 per cent and 0.814 g/cc respectively.

4.3.2 Chemical aspects

4.3.2.1 Determination of protein

The total protein content of *Jatropha* seed was found to be 14.58 per cent. The total protein content in kernel and shell was 12.26 and 2.32 per cent respectively.

4.3.2.2 Determination of carbohydrate

The total carbohydrate content of seed kernel and shell was 10.43 per cent and 1.95 per cent respectively. So, total carbohydrate content of seed is 12.38 per cent.

4.3.2.3 Determination of free fatty acid

The crude oil extracted from the seed was 37.5 per cent. The analysis of seed oil for free fatty acid content showed 8.54 per cent in kernel and 0.96 per cent in shell.

Table 10. Protein, carbohydrate and free fatty acid content of seed

Chemicals	**Kernel**	**Shell**	**Total**
Protein (%)	12.26	2.32	14.58
Carbohydrate (%)	10.43	1.95	12.38
Free fatty acid (%)	08.54	0.96	09.50

Discussion

DISCUSSION

The findings of the present investigation titled "Floral biology and seed technological aspects of *Jatropha curcas* Linn." are discussed below:

5.1 Phenology

The ecological significance of phenological research lies in the fact that it constitutes a dynamic approach for evaluating plant response to the local environment.

It was observed that, *Jatropha curcas* plants displayed all the periodical events viz., leaf shedding, leaf flushing, flowering and fruiting two times a year. The mean duration of leaf shedding was 53.5 days and 36.1 days respectively in first and second season. The time and duration of different periodical events varies with agro-climatic zones (Kumar *et al*., 2003). The long leaf shedding including leaf less duration displayed by *J. curcas* in first season might be due to lower soil moisture content as it was not rainy season. Sharma and Khanduri (2007) reported that the phenological events of a species are markedly affected by microclimate, viz. north and south-facing slopes, precipitation (seasonal variation in water availability), altitude and topography. These features also could be used to explain the longer leaf less season displayed by *J. curcas*.

Leaf flushing in *J. curcas* in the first season was noticed for 21.8 days from March 1st week to April 1st week. The new flush of leaves in second season was for 19.1 days from August 1st week to 3rd week. That is, new flushing of leaves started when plants are still shedding older leaves. The synchronization of leaf flushing with leaf shedding seems to be related to moisture, temperature and photoperiod.

The flowering appeared in synchronization with leaf flushing. This may be due to variation in temperature. Phenological events are frequently controlled by

temperature. Each phenophase is scheduled to occur at a certain temperature range, above and below which it is replaced by other phenophases. In *J. curcas* flowering in the first season started from March 2nd week and continued till third week of May. In second season it was from August 2nd week to October 3rd week. The mean duration of flowering in first and second season was 61.5 days and 64 days respectively. Even though there was no difference in duration of flowering in first and second season, the abundance of flower was more in second season. This might be due to microclimatic (such as temperature, humidity, rainfall, day length, soil moisture and wind speed) which exposes plants to regular periodic changes in the quality and abundance of resources. All these factors are known to play a role alone or in combination in triggering phenological changes. Raju and Ezradanam (2002) reported that *J. curcas* flowers during the rainy season with concentrated flowering from late July to late October in Vishakhapatnam. Bhattacharya *et al*. (2005) reported *J. curcas* in flowers during July to September in National Botanic Garden, Lucknow.

In the first season, fruits appeared in *Jatropha curcas* from May 4th week to July 1st week where as, in 2nd season fruiting was noticed from October 2nd week to November 3rd week. Kun *et al*. (2007) had reported that *J. curcas* can bear fruits twice a year, from March to April and from September to October and from August-September and from March-April of the following year. Fruit set started in the last week of May to the first week of June and lasted for two months in neem (Sharma and Khanduri, 2007).

The fruits were found to be attached to the plants for 20.8 days in first season and 42.3 days in second season. Huge difference was also observed in the duration of fruiting in first and second season. The late maturation and lengthy retention of fruits may be attributed to the micro-climatic variations. However, further investigations are needed before arriving at definite conclusions. Sharma

and Khanduri (2007) stressed emphatically that the phenological activities in *A. indica* are largely governed by climatic factors. The rise in temperature during early summers induced growth, whereas the decline in temperature during early winters terminated it. As a result, leaf and fruit drop, and dormancy followed.

5.2 Floral biology

5.2.1 Inflorescence characters

The inflorescence is recemose with dichasial cyme pattern. Raju and Ezradaman (2002), Bhattacharya *et al*. (2005) and Chang-wei *et al.* (2007) have comfirmed this observation. The inflorescence is monoecious, both male and female flowers are produced in the same inflorescence with protandry, male flower mature first (Raju and Ezradaman, 2002). In an average, inflorescence has taken 18.9 days for its development from visual stage of initiation and average time taken for the full bloom of inflorescence was 14.2 days. Length of these processes may be varied in different locality which is controlled by microclimate.

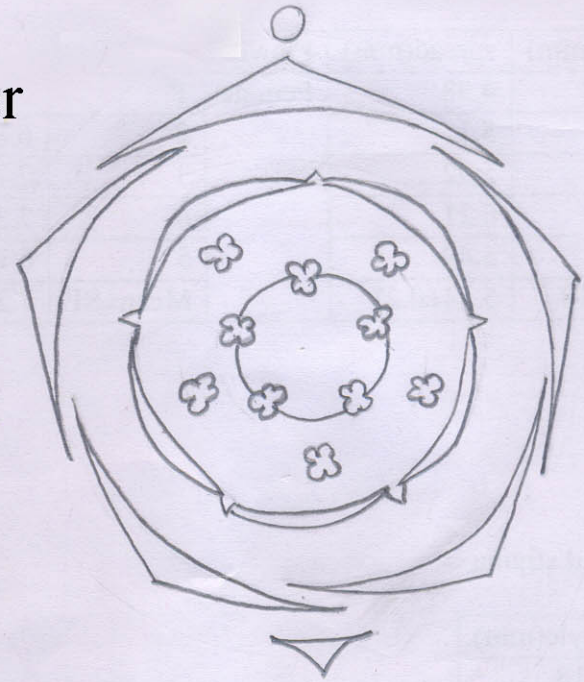
The average number of male flowers and female flowers per inflorescence were 136.4 and 8 respectively. Chang-wei *et al*. (2007) reported the average number of female flowers and male flowers per inflorescence in *J. curcas* as 8 (2–17) and 184 respectively. In this present study the average male to female flower ratio was 17:1. A study by Raju and Ezradaman (2002) also reported nearly similar value.

5.2.2 Floral morphology

The male flower is greenish white, odourless and salvar shaped with its average length and spread of 6.95 mm and 5.54 mm respectively. The sepals are arranged in imbricate aestivation. The petals are valvate and connitent at the flower base forming a short tube. Stamens are ten, diadelphous, arranged in two tiers of five each. The outer tier is free, while the inner tier is united. The anthers

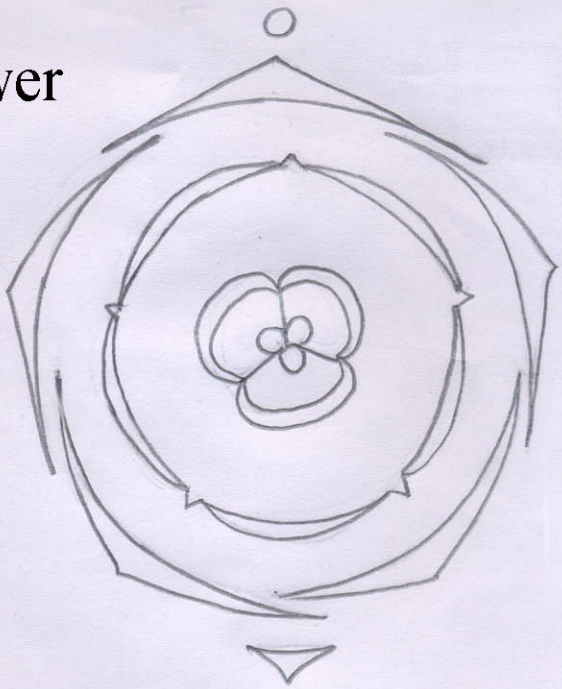
Fig. 2. Floral diagram of *Jatropha curcas*

Male flower



F.F :- $\oplus \delta K_5 C_{(5)} A_{5+(5)} G_0$

Female Flower



F.F :- $\oplus \varphi K_5 C_{(5)} A_0 \underline{G}_{(3)}$

are yellow, dithecous and dorsifixed. The pollen grains are yellow in colour and globular in shape.

Female flower is quite similar to the male flower in shape, colour and slightly fragrant, but is relatively larger showing length and spread of 7.25mm and 6.02 mm respectively. Sepals free and are imbricate. The petals are valvate, forming a small tube at the flower base. The styles and stigmas are both three and free. The stigmas are green, darker than petals and are bifid. The ovary is tricarpellary, united, one ovule in each chamber arranged in axile placentation. The floral base is villose, and contains five elliptical glands under the ovary. These findings are in concurrence with the observations by Raju and Ezradaman (2002), Bhattacharya *et al*. (2005) and Chang-wei *et al.* (2007). Figure 1 show floral diagram of male and female flower of *Jatropha curcas*.

5.2.3 Anthesis, anther dehiscence and stigma receptivity

Anthesis started from 06.50 am and lasted up to 11.50 am. Maximum flowers opened between 08.30 am and 11.00 am. Forenoon pattern of anthesis was noticed and is similar to observation by Raju and Ezradaman (2002) and Bhattacharya *et al*. (2005). Anthesis is an important criterion for judging the onset of pollen release and subsequent dispersal, which is a prerequisite for plant breeding system.

Anthers dehisced at a mean time of 1.28 hrs after anthesis. Raju and Ezradanam (2002) reported that the anthers in *J. curcas* dehisce an hour later by longitudinal slits.

On an average, stigma attained receptivity at 01.20 to 2.25 hours after anthesis and remained so for 2-3 days. Bhattacharya *et al*. (2005) reported that the stigma of *J. curcas* flower becomes receptive 1-2 h. after flower opening. Knowledge of anthesis, anther dehiscence and stigma receptivity is relevant to the

study of pollination, developing a functional model for forecasting pollen concentrations and to understand more about the ecological background of pollen dispersal.

5.2.4 Pollen morphology and fertility

The pollen grains were observed to be yellow and globular or spheroidal which are in conformation to the observations made by Raju and Ezradanam (2002). In the present study the estimated average number of pollen grains per flower was 1601. Bhattacharya *et al*. (2005) had reported that each *J. curcas* flower produced 1617±100 pollen grains. Pollen morphology plays an important role in relation to pollinators but it is a field still to be explored. The pollen exhibited 91.06 per cent fertility in the present observation.

5.2.5 Mode of pollination

In the present study the inflorescence were observed for fruit set per cent in different modes of pollination viz., cross pollination, self pollination and wind pollination. In open pollination, the percentage of fruit set was 4.95 in relation to total number of flower buds established. The percentage of fruit set in self pollination and wind pollination was 3.7 and 3.28 respectively (Figure 2). So the mode of pollination in *Jatropha curcas* is both cross pollination and self pollination. Raju and Ezradanam (2002) reported that *Jatropha curcas* is predominantly cross pollinating. They also stated that seed quality depends mostly on cross-pollination in *J. curcas* but selfing is also compatible. The plant is predominantly out breeding and this is clearly shown in many of the reproductive traits such as absence of auto deposition of pollen due to unisexual nature, high attractiveness to pollinators, delayed stigma receptive period and morphological

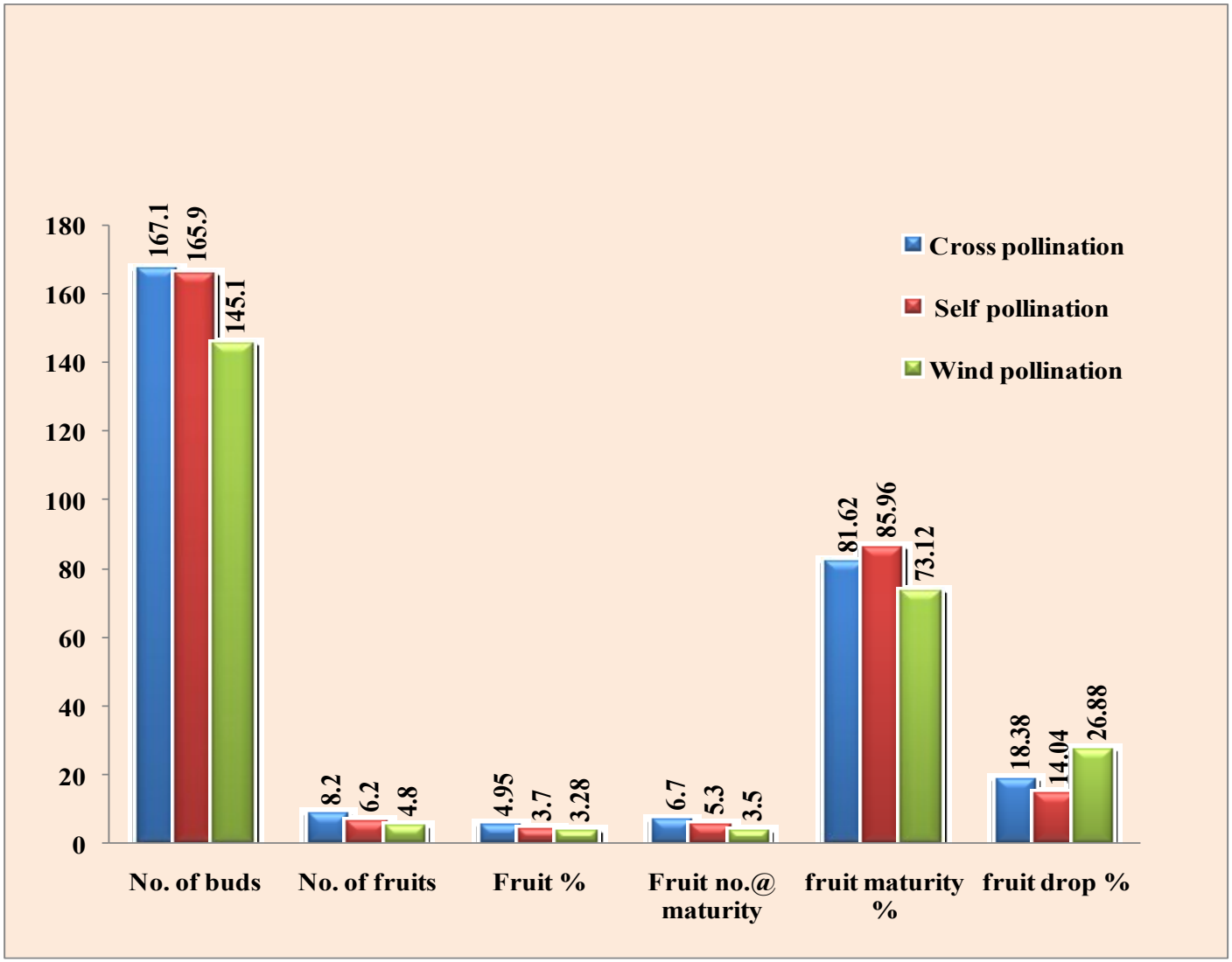


Figure 2. Number and per cent of fruit set & fruit drop per cent in different modes of pollination in *Jatropha curcas*

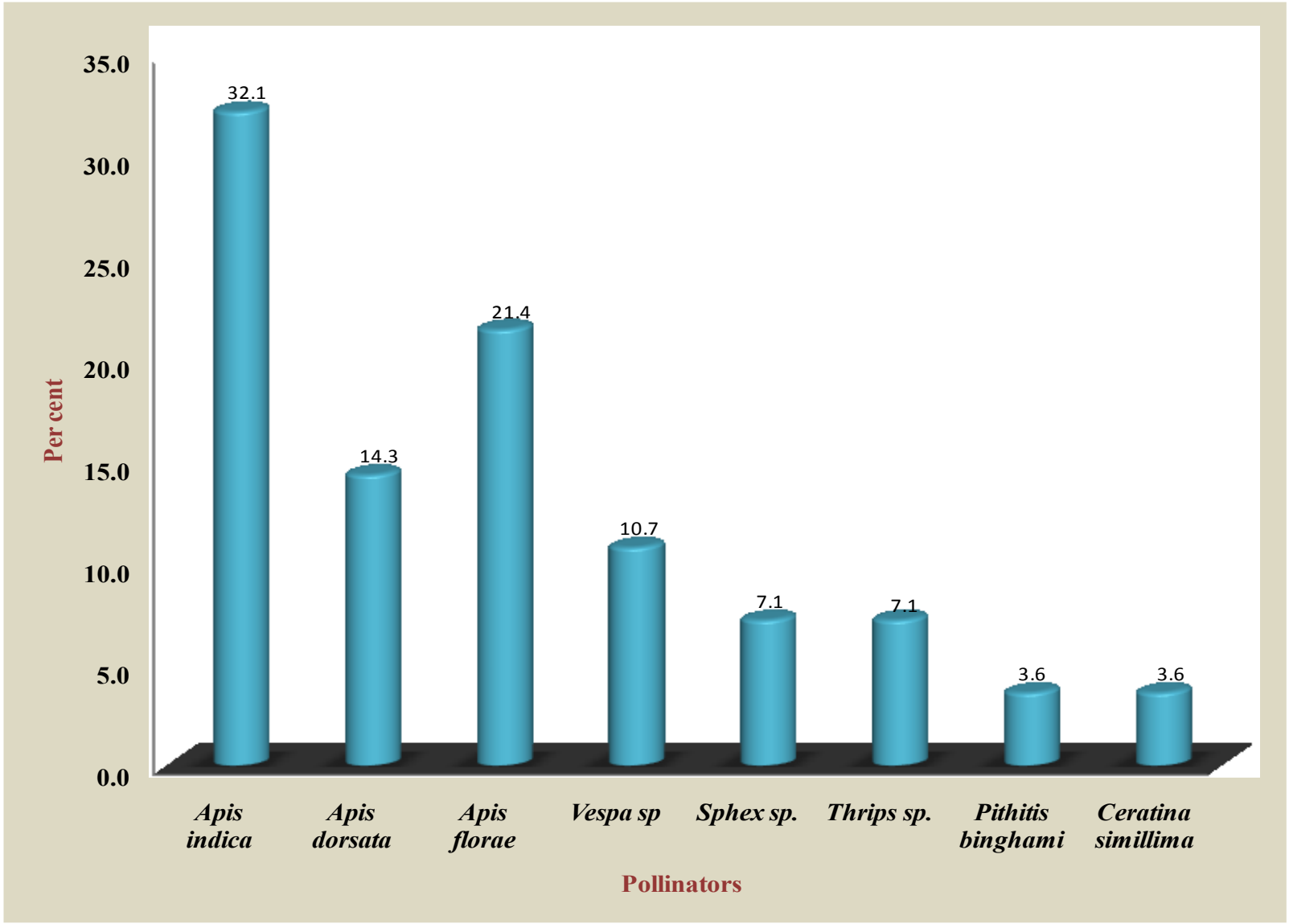


Figure 3. Per cent of different pollinators visiting *Jatropha curcas* flower

differentiation of receptive stigma for proper pollen reception (Bhattacharya *et al*., 2005).

5.2.6 Flower pollinators

The individual flowers are grouped together in recemose inflorescence, an arrangement which promotes attraction and foraging rate by the foragers. A plant with monoecious sexual system essentially requires an agent for pollen transfer from male to female flowers. In the present study the floral visitors included bees, ants, wasps, thrips and flies (Figure 3). They foraged daily during day light hours from 0730 to 1800 h. Among the different floral visitors honeybees (*Apis indica*, *A. dorsata*, and *A. florae*) were observed as the predominant insect pollinators. Bhattacharya *et al*. (2005) also reported that honeybees (*Apis dorsata*, *A. florea* and *A. mellifera*) were most common and effective pollinators in *J. curcas*. The bees, by collecting pollen and nectar and moving between male and female flowers effected pollination. Foraging activity of bees in the present study is largely confined to the forenoon period and this can be related to the period of nectar secretion.

5.2.7 Fruiting behaviour

5.2.7.1 Fruit set

In the present study the average number and percentage of fruit set in different modes of pollination were highest in cross pollination (natural pollination) followed by self pollination and was least in wind pollination. The natural fruit set rate indicates that the plant does not suffer seriously from under-pollination. The production of female flowers in small number, surrounded by a large number of male flowers seems to be a strategy to ensure pollination to the maximum extent. The stigma receptivity lasting two to three days also additionally provides opportunities for pollination, if not pollinated on the first and second day.

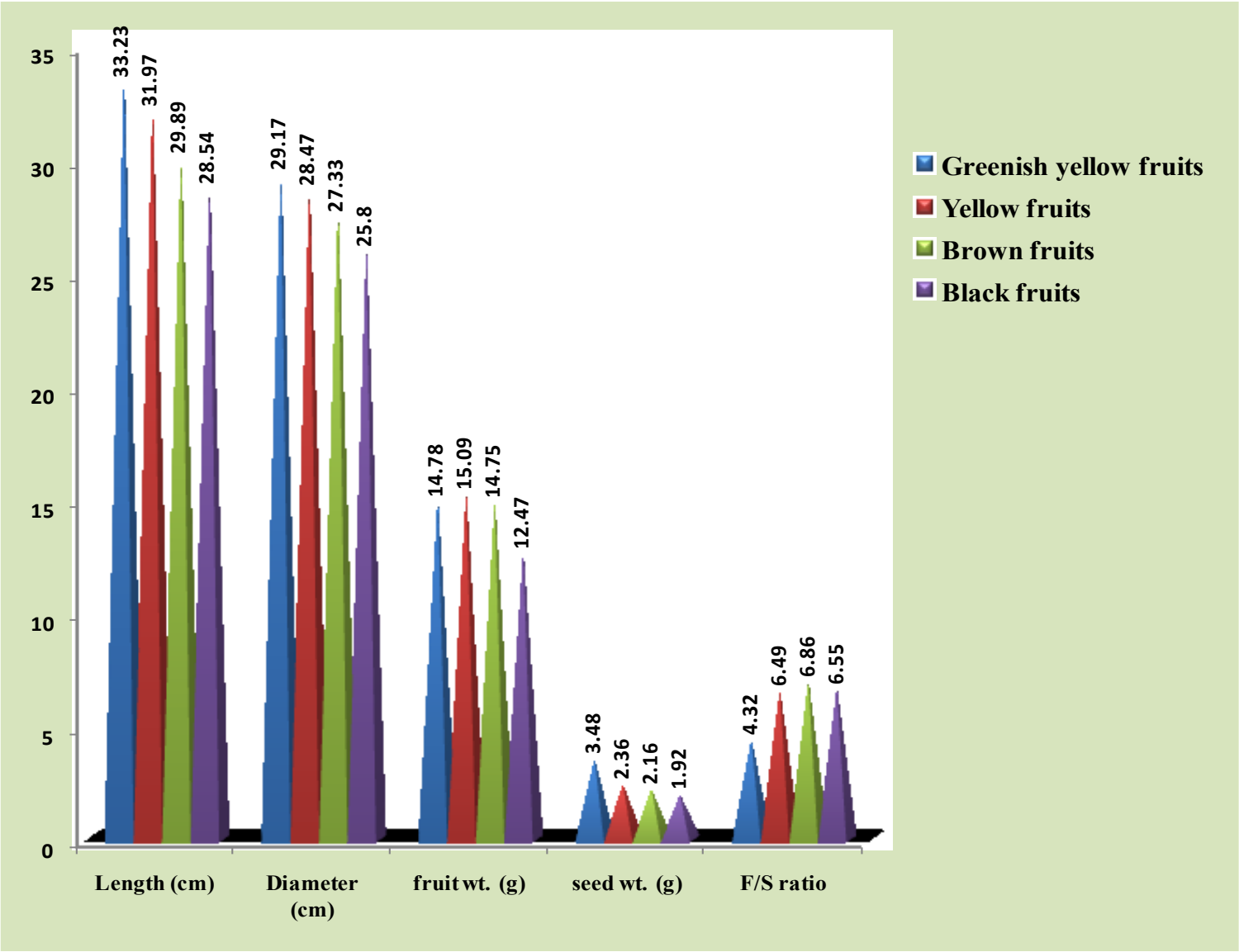


Figure 4. Fruit characteristics of *Jatropha curcas* at different maturity stages

Similar observations are also made by Raju and Ezradaman (2002) and Bhattacharya *et al*. (2005). They also reported that the fruit set rate is related to the number of female flowers produced by the plant. Bhattacharya *et al*. (2005) has also reported that the *J. curcas* flower-fruit ratio is 10:1.

This study also indicates that pollen is deposited in sufficient amount, which is visible by its yellow colour even to the naked eye. Pollen transfer between male and female flowers has a great bearing on the net percentage of fruit set in cross pollination. This observation was also made by Raju and Ezradaman (2002). The average number of days taken from flower initiation to fruit set in *J. curcas* was 13.5. As these processes are sensitive to climatic conditions, this observation has to be investigated further. Sharma and Khanduri (2007) reported that the number of days between flowering and fruit set in *J. curcas* varied significantly in different sites.

5.2.7.2 Fruit development and fruit drop

Jatropha curcas fruit attained maturity (yellow to brown colour) in 16 to 19 days after fruit set. The results obtained in this study are contrary to the results obtained by other workers. Raju and Ezradaman (2002) reported that ratanjyot fruits mature in 2 to 3 months after fruit set. This difference might be attributed to variation in climatic conditions and soil moisture content at Vellanikkara during the study period which needs to be investigated.

Jatropha fruit showed dimensional variation at different maturity levels (Figure 4). Generally, it has been known that as fruit matures its dimensions will be progressively decreasing.

It was observed that the per cent of fruits attaining maturity was 80.23. There was significant difference in percentage of fruits attaining maturity (out of average number of fruit set) in different modes of pollination. The fruit set through wind pollination showed least per cent of fruits attaining maturity and highest per

cent of fruit drop. The more compatibility nature of *Jatropha* flower to cross pollination through insect pollinators resulted in significant difference among different modes of pollination.

5.3 Seed technological aspects

5.3.1 Seed germination studies

In the present study cent per cent germination was obtained for the seeds collected from yellow coloured fruits, followed by 96.67 per cent germination from seeds of brown coloured fruits (Figure 5). It was observed that the germination per cent and capacity showed significant variation with the different maturity level. Gurunathan (2006) reported the germination percent of *J. curcas* seeds collected at different maturity level as seed from yellowish brown – 88 per cent, seeds from brown fruits-84 per cent and seeds from black dry fruits-74 per cent. He also reported the effect of maturity stage on germination per cent was found to be significant.

Other researchers working with *Jatropha* (Kathiravan, 2004 and Geethanjali *et al*., 2003) has also recorded the highest germination per cent in seeds from yellow and brown coloured fruits. The main reason responsible for less germination per cent at different maturity level may be moisture content of seeds, environmental factors and pathogen. The fresh greenish yellow coloured fruits might be having incomplete fillingness of seeds, kernel weight etc., which can be responsible for their reduced germination per cent.

On the other hand the black coloured fruits are having less moisture compared to yellow and brown coloured which result in reduced germination per cent. Optimum moisture content always results in higher germination per cent. Gurunathan (2006) reported higher germination for heavier seeds (yellow and brown coloured fruits) than in the lighter seeds (black coloured fruits) in *J. curcas*. Similar results were found in neem by Ponnammal *et al.* (1993). Environmental

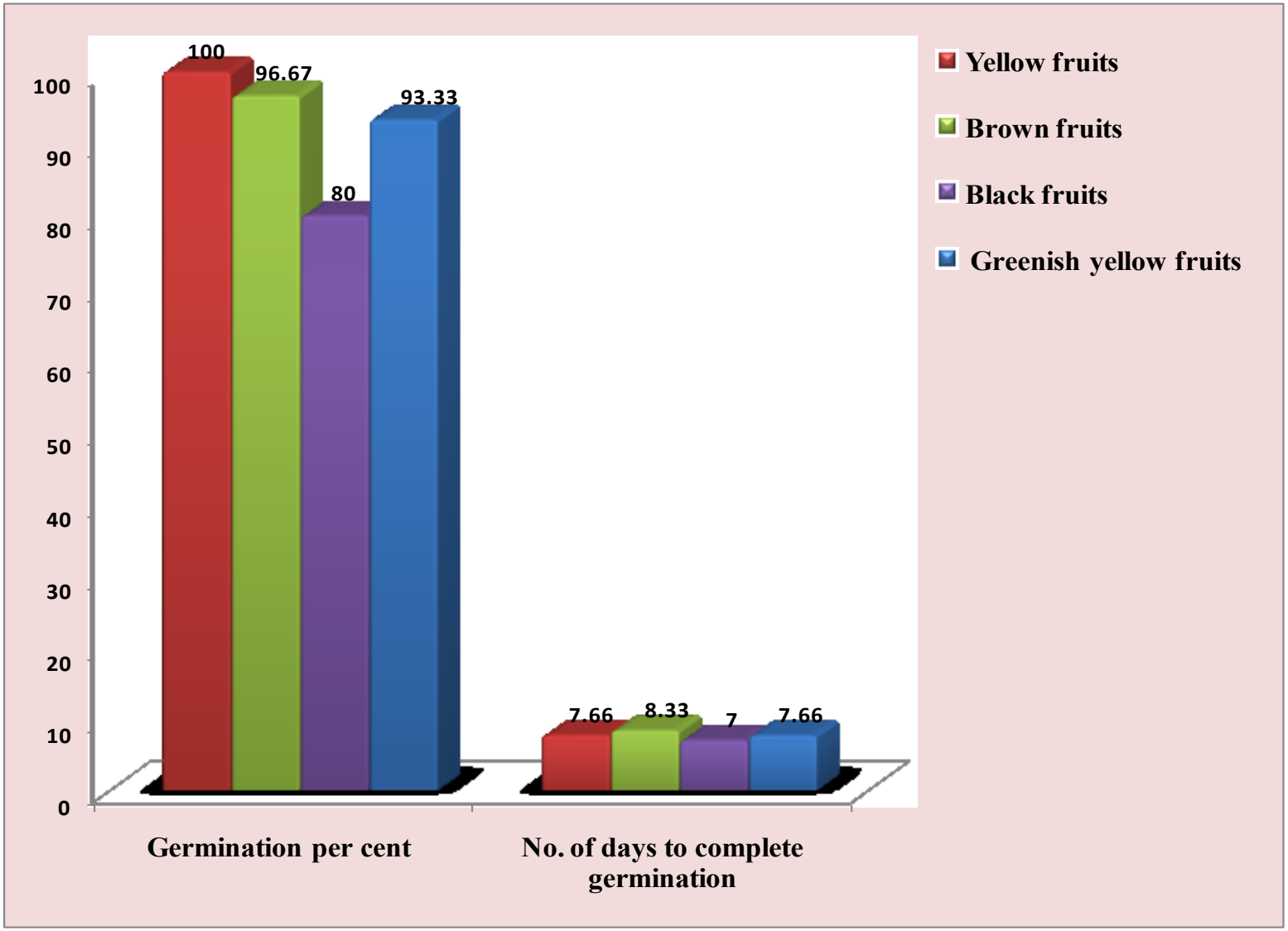


Figure 5. Germination percent and number of days taken to complete germination at different maturity levels of *Jatropha curcas* seed

factors during seed production are also having a significant influence on seed quality for germination. In the study, it was also observed that the black coloured fruits were found to be attacked by some fruit boring insects (*Scutellera nobilis* Fabr.) and also by a fungus. This also might be a reason for decrease in germination capacity. The seeds extracted from brown and black coloured fruits started to germinate two days after sowing, where as it took three days after sowing in case of seeds extracted from greenish yellow and yellow coloured fruits.

5.3.2 Seed dimension

It was observed that as *Jatropha curcas* fruit transformed from greenish yellow to yellow, brown and black, the size of the seed decreased and this was statistically significant also (Figure 6). Kathivaran (2004) also reported the variation in seed dimension in *J. curcas*. Average highest and lowest single seed weight and hundred seed weight were found in greenish yellow coloured fruits and black coloured fruits respectively. The result of the present study is in conformity with the results obtained by Kaushik (2003).

5.3.4 Seed moisture content and seed density

The moisture content of seed is an important factor that determines the quality of seed both orthodox and recalcitrant. In the present study the average moisture content of the seed was found to be 13.39 per cent. The moisture content required for storage is specific for each crop, which hastens the deterioration of seed in storage. Singh (2008) reported 4.5 per cent moisture content in *J. curcas* seed. Analysis of *J. curcas* seed by Sharma (2005) revealed 6.2 per cent moisture content. This variation in our study may be due to the agro climatic condition of the region as well as season and maturity of seed collection. As seeds were collected during rainy season, high moisture content was noticed in the present study. Lal and Biswarup (2006) collected the seeds from different states to determine the moisture content and other parameters. They reported significant

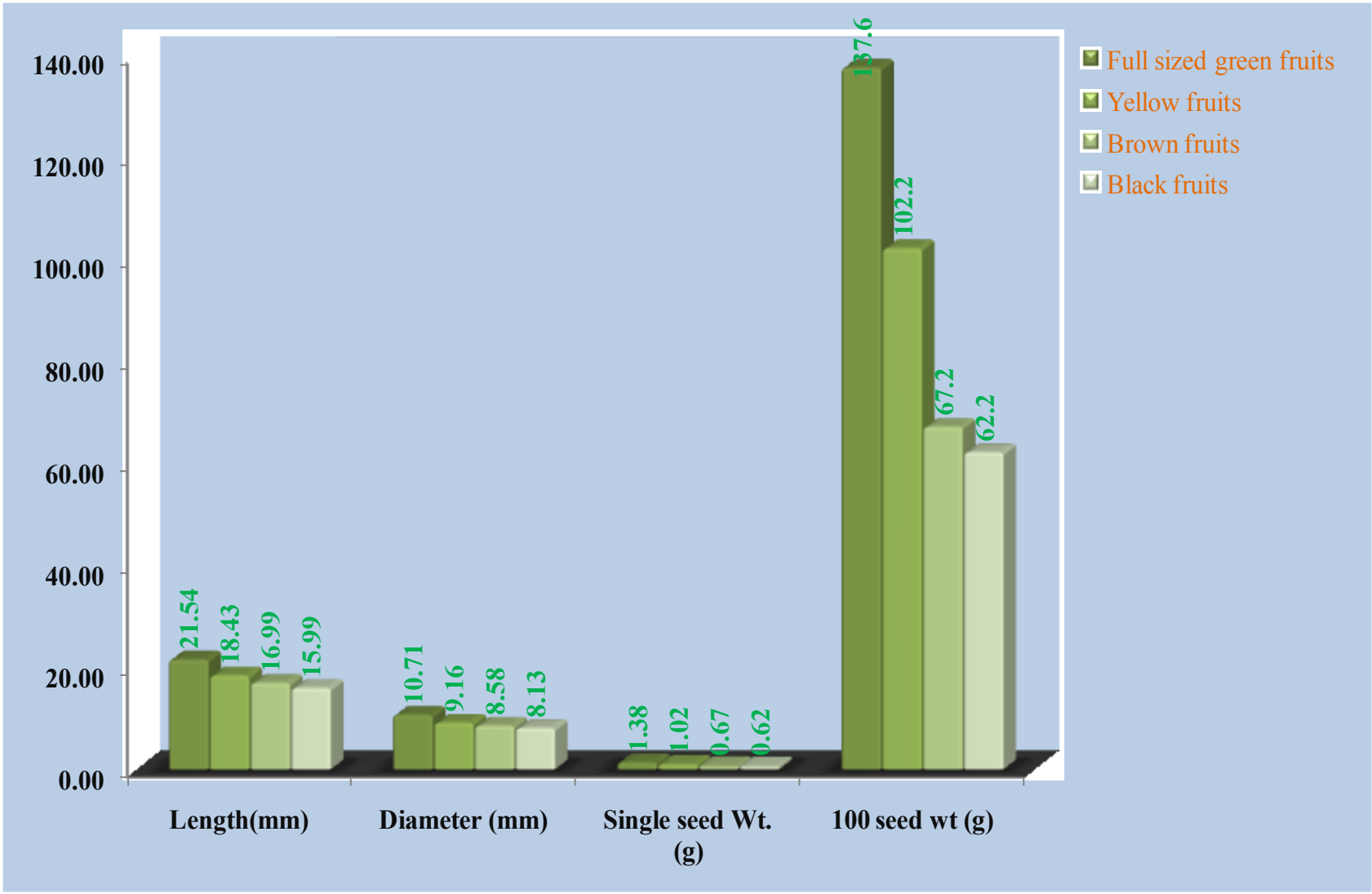


Figure 6. Seed dimensions at different maturity level of *Jatropha curcas*

variation in the moisture content of seeds among different states. A small change in seed moisture content has a large effect on the storage life of the seeds. Therefore it is important to know the moisture content in order to make a reasonably accurate prediction of the possible storage life of seed. A seed with less moisture content allows little or no insect activity.

The average density of seed was observed as 0.814 g/cc in the present study. Sirisomboon *et al*. (2007) also reported nearly similar results with respect to seed density (1.04 g/cc) in *J. curcas*. The average seed density of 1.15 g/cc was recorded in *Saraca asoca* by Kumar (2004). Seed density might be one of the factors influencing the amount of protein, carbohydrate and fatty acid. Li and Burton (2002) reported that seed density in *Glycine max* (L.) Merr. is a component of grain yield that is correlated positively with seed protein concentration.

5.3.5 Protein, carbohydrate and free fatty acid content

The total protein content of *Jatropha curcas* seed was found to be 14.58 per cent. Of which, kernel has 12.26 per cent protein and shell 2.32 per cent protein. Lal and Biswarup (2006) also reported 15.27 to 16.43 per cent protein content of *Jatropha* seed. Similar reports were also made by Zippel and Deters (2006) and Singh (2008) on *Jatropha* seed. Ogbobe and Akano (1993) reported that the seed of *J. gossipifolia* contained 13.4 per cent protein. However, the results obtained from this study are also in contradiction to other workers. Gubitz *et al*. (1999) reported 22.2 to 27.2 per cent and 4.3 to 4.5 percent protein from seed kernel and shell respectively. Martínez-Herrera *et al*. (2006) revealed 31–34.5 per cent protein content in seed. Gandhi *et al*. (1995) recorded 23.3 per cent protein. This variation might be due to both environmental factors (climate, topography and soil) and genetic constitution of the plant, which needs to be investigated.

In the present study the total carbohydrate content of seed was 12.38 per cent. Gandhi *et al*. (1995) revealed 12.1 per cent carbohydrate in *Jatropha* seed.

Nearly similar value of 16.59 per cent of carbohydrate was reported by Singh (2008) in Jabalpur. Sharma (2005) also reported nearly similar value (17 per cent). The present result varied strongly from other workers also. Akintayo (2004) reported 7.99 per cent carbohydrate where as Martínez-Herrera *et al*. (2006) revealed below 6 per cent carbohydrate in *Jatropha curcas* seed. The main reasons for this difference may be attributed to environmental conditions (locality factors) and genetic variability. The protein and carbohydrate content of seed may influence germination capacity and germination rate. However, further investigation is required to draw a valid conclusion. Variation in oil content, protein and carbohydrate content are due to agro climatic conditions of the locality (Kumaran, 1991 and Kumar *et al*., 2003).

Jatropha curcas being the choicest biofuel crop, oil content is one of the most important criteria for the selection of the species. *Jatropha* contains about 30-40 per cent of oil on weight basis (Subramanian *et al*., 2005). In the present study the percentage of oil content on weight basis was observed to be 37.5 per cent. Chaudhari and Joshi (1999) also reported 35-40 per cent oil on weight basis. Similar results (31-35 per cent) were also observed by Lal and Biswarup (2006).

In the present analysis it found that the amount of free fatty acid was 8.54 per cent in kernel and 0.96 per cent in shell. Berchmans and Hirata (2008) reported 14.9 per cent free fatty acid from *Jatropha* seed oil. Foidl *et al*. (1996) found 0.29 – 0.49 and 0.60-1.27 per cent of free fatty acids respectively in two varieties of *Jatropha curcas* namely Caboverde and Nicaragua. This wide difference between the different studies can be due to season of seed collection, seed maturity stage and also environmental and genetic causes.

Seed production to obtain biodiesel through available tree born oil seeds viz., *Jatropha curcas* is not sufficient to meet the demands of alternative energy source for diesel. High yielding varieties of *Jatropha curcas* has to be released. In

this context, study on floral biology plays vital role. However, during the course of this study, some aspects of reproductive biology have been attempted. Hence, still detailed study may be required to draw valid conclusion. In addition the timing of different periodical events can be used for further investigation.

Summary

SUMMARY

The present study on "Floral biology and seed technological aspects of *Jatropha curcas* Linn." was carried out in the Department of Forest Management and Utilization, College of Forestry, Thrissur during the year 2006-2007.

The salient findings of the experiment are summarized here under.

1. The plants started to shed leaves from January 2nd week and continued till March 2nd week in the first season. Whereas, in the second season leaf shedding was noticed from May 3rd week to July 4th week.

2. Leaf flushing in first season was noticed from March 1st week to April 1st week. The new flush of leaves in second season was from August 1st week to 3rd week.

3. Flowering in first season started from March 2nd week and continued till third week of May. In second season it was from August 2nd week to October 3rd week.

4. In first season fruits appeared from May 4th week to July 1st week where as, in 2nd season fruiting noticed from October 2nd week to November 3rd week.

5. The inflorescence is racemose with dichasial cyme pattern. The inflorescence is monoecious, both male and female flowers are produced in the same inflorescence. The average number of male and female flowers per inflorescence was 136.4 ± 10.82 and 8 ± 0.71 respectively. The average male to female flower ratio is 17:3 ± 1.37.

6. On an average, an inflorescence took 18.9 ± 0.67 days for its development from visual stage of initiation. Average time taken for the full bloom of inflorescence was 14.2 ± 0.75 days.

7. The male flower is greenish white, odourless and salvar shaped with its average length and spread of 6.95 ± 0.19 mm and 5.54 ± 0.23 mm respectively. The flower is actinomorphic and incomplete. The sepals and petals are five (pentamerous) and free. The sepals are arranged in imbricate aestivation. The petals are valvate and connitent at the flower base forming a short tube. Stamens are ten, diadelphous, arranged in two tiers of five each. The outer tier is free, while the inner tier is united. The anthers are yellow, dithecous and dorsifixed. The pollen grains are yellow and globular.

8. Female flower is quite similar to the male flower in shape, colour and slightly fragrant, but is relatively larger showing length and spread of 7.25 ± 0.19 mm and 6.02 ± 0.28 mm respectively. Sepals free and are imbricate. The petals are valvate, forming a small tube at the flower base. The styles and stigmas are both three and free. The stigmas are green, darker than petals and are bifid. The ovary is tricarpellary, united, one ovule in each chamber arranged in axile placentation. The floral base is villose, and contains five elliptical glands under the ovary.

9. The average length of stamen and styles is 5.07 ± 0.24 mm and 6.46 ± 0.16 mm respectively.

10. Anthesis started from 06.50 am and lasted up to 11.50 am. Maximum flowers opened between 08.30 am and 11.00 am. Anthers dehisced at a mean time of 1.28 hr after anthesis. Stigma attained receptivity between 01.20 pm and 2.25 pm and remained so for 2-3 days. On an average, stigma becomes receptive 2.1 ± 0.12 hr after anthesis.

11. The estimated average number of pollen grains per flower is 1601 ± 70. Pollen exhibited 91.06 ± 2.42 per cent fertility.

12. In open pollination, the percentage of fruit set was 4.95 in relation to total number of flower buds established. Where as the percentage of fruit set in self pollination and wind pollination was 3.7 and 3.28 respectively. The inflorescence produced, on an average 8.2, 6.2 and 4.8 fruits through cross pollination, self pollination and wind pollination respectively.

13. The floral visitors included bees, ants, wasps, thrips and flies. They foraged daily during day light hours from 0730 to 1800 h. Among the different floral visitors honeybees (*Apis indica*, *A. dorsata*, and *A. florae*) were observed as the predominant insect pollinators. *Apis indica* alone account for 32 per cent visit.

14. The average number and percentage of fruit set in different modes of pollination showed highest in cross pollination (6.7 and 85.96%) followed by self pollination (5.3 and 81.62%) and least in wind pollination (3.5 and 73.12%).

15. The average number of days taken from flower initiation to fruit set was 13.5 ± 0.47. The fruit attained yellow to brown colour at 16 to 19 days after fruit set.

16. The average maximum length (33.23 mm) and diameter (29.17 mm) were recorded in greenish yellow coloured fruit followed by yellow coloured fruit with 31.97 mm length and 28.47mm diameter. The least length (28.54 mm) and diameter (25.8 mm) were seen in black coloured fruit.

17. The highest per cent of fruits attaining maturity (85.96) and least percentage of fruit drop (14.04) was observed in cross pollination followed

by self pollination (81.62 and 18.38 respectively). The fruit set through wind pollination showed least per cent of fruits attaining maturity (73.12) and highest per cent of fruit drop (26.88).

18. Hundred per cent germination was achieved in the seeds collected from yellow coloured fruits, followed by 96.67 per cent germination from seeds of brown coloured fruits. The least germination percentage (80%) was obtained from seeds of black coloured fruits.

19. The seeds extracted from brown and black coloured fruits started to germinate two days after sowing, where as three days after sowing in case of seeds extracted from greenish yellow and yellow coloured fruits.

20. The maximum seed length (21.54 mm) and diameter (10.71 mm) were recorded in greenish yellow coloured fruits, where as it was minimum in black coloured fruits (15.99 mm and 8.126 mm).

21. Average highest and lowest single seed weight and hundred seed weight were found in greenish yellow coloured fruits (1.376 g and 97.45 g) and black coloured fruits (0.622 g and 78.37 g) respectively.

22. The average moisture content of the *Jatropha curcas* seed was found to be 13.39 per cent and the average density of seed was observed as 0.814 g/cc.

23. The total protein content of seed was 14.58 per cent. The total protein content in kernel and shell was 12.26 and 2.32 per cent respectively.

24. The total carbohydrate content of seed kernel and shell was 10.43 per cent and 1.95 per cent respectively.

25. The crude oil extracted from the seed was 37.5 per cent. Free fatty acid content of kernel and shell was 8.54 per cent and 0.96 per cent respectively.

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Appendices

Appendix i: Meteorological data (mean monthly)

Source: Department of Agricultural Meteorology, KAU, Vellanikkara.

Months	Max. Temperature (^{0}C)		Min. Temperature (^{0}C)		RH (%)		Rainfall (mm)		Rainy days		Sunshine (hr.)		Wind speed (km/hr.)	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
January	32.5	32.3	22.0	21.7	54	59	0.0	0	0	0	268.5	292.9	9.2	7
February	34.0	33.6	22.2	22.9	55	61	0.0	29.7	0	3	275.5	236.9	4.9	4.5
March	36.0	33.2	24.4	23.4	63	64	0.0	205.3	0	7	254.4	212.5	4.3	4.8
April	35.1	-	25.0	-	69	-	61.0	-	4	-	230	-	4.3	-
May	32.8	-	24.6	-	76	-	240.5	-	10	-	205.1	-	3.7	-
June	30.1	-	23.5	-	84	-	826.5	-	23	-	105.5	-	3.8	-
July	28.4	-	22.9	-	88	-	1131.9	-	28	-	22.1	-	3.2	-
August	29.0	-	22.8	-	84	-	549.7	-	19	-	100.5	-	2.7	-
September	29.4	-	22.9	-	86	-	765.9	-	23	-	75.1	-	3.0	-
October	30.5	-	22.5	-	79	-	383.8	-	14	-	135.2	-	3.2	-
November	31.7	-	21.6	-	67	-	24.8	-	3	-	239.2	-	4.5	-
December	31.6	-	22.7	-	56	-	8.7	-	1	-	207.1	-	8.6	-

Appendix iii: ANOVA for Fruit characteristics at different maturity stages

		Sum of squares	df	Mean square	F Value	Sig.
Length	Between groups	131.6	3	43.867	14.558	0.000
	Within groups	108.478	36	3.013		
	Total	240.078	39			
Diameter	Between groups	65.078	3	21.693	7.892	0.000
	Within groups	98.952	36	2.749		
	Total	164.03	39			
Fruit wt	Between groups	43.993	3	14.664	5.659	0.002
	Within groups	93.282	36	2.591		
	Total	137.275	39			
Seed wt	Between groups	14.322	3	4.774	25.515	0.000
	Within groups	6.736	36	0.187		
	Total	21.057	39			
F/R ratio	Between groups	40.774	3	13.591	26.866	0.000
	Within groups	18.212	36	0.506		
	Total	58.987	39			

Appendix iv: ANOVA for germination per cent and Germination capacity

ANOVA						
		Sum of squares	df	Mean square	F Value	Sig.
No. of seeds germinated	Between groups	6.917	3	2.306	5.533	0.023
	Within groups	3.333	8	0.417		
	Total	10.25	11			
Germination Percent	Between groups	691.667	3	230.556	5.533	0.023
	Within groups	333.333	8	41.667		
	Total	1025	11			
Days taken to complete germination	Between groups	2.667	3	0.889	0.889	0.005
	Within groups	8	8	1		
	Total	10.667	11			

Appendix v: ANOVA for daily germination and number of days taken to complete germination

ANOVA						
		Sum of squares	df	Mean square	F Value	Sig.
Greenish yellow coloured fruits	Between groups	4200	8	525	14.175	0.013
	Within groups	666.667	18	37.037		
	Total	4866.667	26			
Yellow coloured fruits	Between groups	4133.333	8	516.667	17.438	0.024
	Within groups	533.333	18	29.63		
	Total	4666.667	26			
Brown coloured fruits	Between groups	2696.296	8	337.037	7.583	0.000
	Within groups	800	18	44.444		
	Total	3496.296	26			
Black coloured fruits	Between groups	1933.333	8	241.667	9.321	0.000
	Within groups	466.667	18	25.926		
	Total	2400	26			

Appendix vi: ANOVA for seed dimensions at different maturity level

ANOVA						
		Sum of squares	df	Mean square	F Value	Sig.
Length	Between groups	87.797	3	29.266	35.134	0.00
	Within groups	13.327	16	0.833		
	Total	101.124	19			
Diameter	Between groups	19.079	3	6.36	18.219	0.00
	Within groups	5.585	16	0.349		
	Total	24.664	19			
Single seed weight	Between groups	1.843	3	0.614	58.663	0.00
	Within groups	0.168	16	0.01		
	Total	2.011	19			
100 seed weight	Between groups	17430.6	3	5843.533	58.663	0.00
	Within groups	1575.6	16	104.725		
	Total	19106.2	19			

Abstract

FLORAL BIOLOGY AND SEED TECHNOLOGICAL ASPECTS OF *Jatropha curcas* Linn.

By

PUTTASWAMY, H

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Forestry

Faculty of Agriculture
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ABSTRACT

The present study entitled "Floral biology and seed technological aspects of *Jatropha curcas* Linn." was carried out in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the period of 2006-2007.

The plant displayed phenological cycle twice a year for all periodical events viz., leaf shedding, leaf flushing, flowering and fruiting. However, the duration of each stage was high in second season as it coincided with rainy season. Fruiting appeared from 4th week of May to 1st week of July in first season and from 2nd week of October to 3rd week of November in second season.

The inflorescence is monoecious with protandry and is racemose with dichasial cyme pattern. The average number of male flowers and female flowers per inflorescence were 136.4 ± 10.82 and 8 ± 0.71 respectively. The inflorescence is having two tiers viz., large tier and small tier. The average length and spread were recorded as 7.624 ± 0.84 cm and 6.373 ± 0.55 cm in large tier, and 6.101 ± 0.99 cm and 4.357 ± 0.36 cm in small tier respectively. In an average, inflorescence has taken 18.9 ± 0.67 days for its development from visual stage of initiation and the time taken for the full bloom of inflorescence was 14.2 ± 0.75 days. The male flower is greenish white, odourless and salvar shaped. Flower is actinomorphic and incomplete. The sepals and petals are five (pentamerous) and free. The sepals are arranged in imbricate aestivation. The petals are valvate and connitent at the flower base forming a short tube. Stamens are ten, diadelphous, arranged in two tiers of five each. The outer tier is free, while the inner tier is united. The anthers are yellow, dithecous and dorsifixed. The pollen grains are yellow, globular and inaperturate. Female flower is quite similar to the male flower in shape, color and slightly fragrant, but is relatively larger. Sepals and petals are same as male flower. The styles and stigmas are both three and free. The

stigmas are green, darker than petals and are bifid. The ovary is tricarpellary, united, one ovule in each chamber arranged in axile placentation. The floral base is villose, and contains five elliptical glands under the ovary.

Anthesis started from 06.50 am and lasted up to 11.50 am. Anthers dehisced at a mean time of 1.28 h after flower opening. The stigma attained receptivity between 01.20 pm to 2.25 pm and remained so for 2-3 days. The estimated average number of pollen grains per flower was 1601 ± 70. The pollen exhibited 91.06 ± 2.42 per cent fertility. In open pollination, the percentage of fruit set was 4.95 (highest among different modes) in relation to total number of flower buds established. The flowers exhibited both entomophilous way of pollination and wind pollination. Honeybees (*Apis indica*, *A. dorsata*, and *A. florae*) were observed as the predominant insect pollinators.

The fruit attained yellow to brown colour at 16 to 19 days after fruit set. The average maximum length (33.23 mm) and diameter (29.17 mm) were recorded in greenish yellow coloured fruit followed by yellow coloured fruit with 31.97 mm length and 28.47 mm diameter. The flower drop in inflorescence was 94.01 per cent and only 3.99 per cent of flowers set in to fruits.

Hundred per cent germination was obtained for the seeds collected from yellow coloured fruits, followed by 96.67 per cent germination from seeds of brown coloured fruits. The least germination percentage (80%) was obtained from seeds of black coloured fruits. The maximum seed length (21.54 mm) and diameter (10.71 mm) were recorded in greenish yellow coloured fruits. The average moisture content and density of seed were noted as 13.39 per cent and 0.814 g/cc respectively. The crude oil extracted from the seed was 37.5 per cent. The seed contained protein - 14.58 per cent (kernel-12.26%, shell-2.32%), carbohydrate - 14.58 per cent (kernel-10.43%, shell-1.95%) and free fatty acid – 9.5 per cent (kernel-8.54, shell-0.96).