COMMUNICATION

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 May 2016 | 8(5): 8788–8796

ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

OPEN ACCESS

Pollination ecology of *Derris trifoliata* (Fabaceae), a mangrove associate in Coringa Mangrove Forest, Andhra Pradesh, India

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Abstract: *Derris trifoliata* is a perennial woody climber. It blooms massively for about two weeks in July/August. The flowers are hermaphroditic, feebly protandrous, self-compatible and display a vector dependent mixed breeding system. They close back by the end of the day of anthesis. The forenoon anthesis and pollen and nectar as rewards attract daytime foragers. The nectar feeding foragers require strength to depress the keel petals in order to collect nectar; only those foragers which have the required strength to do so can collect nectar and in the process trip the floral mechanism and effect pollination. When floral explosion occurs, the pollen is somewhat exposed and the pollen feeding foragers then collect it. Both long- and short-tongued bees trip the flowers, collect nectar and effect pollination. Individual flowers that were not tripped by insects set fruit to negligible level. In open-pollination mode, fruit set rate is up to 30-31% only despite the flowers being visited by insect pollinators. Fruits mature quickly within a month. Each fruit contains 1-3 seeds against 6 linearly arranged ovules in the ovary. The fruits are leathery and possess air cavities, the characteristics of which enable them to float in tidal water. They settle at the parent plant if the site is partly or fully exposed or float for dispersal if the site is inundated with tidal water. Seed release occurs when fruits absorb water and the pericarp breaks. Seeds germinate only when they reach a suitable habitat in mangroves.

Keywords: *Derris trifoliata*, entomophily, explosive pollination mechanism, mixed breeding system.

DOI: http://dx.doi.org/10.11609/jott.2277.8.5.8788-8796

Editor: K.R. Sasidharan, Institute of Forest Genetics and Tree Breeding, Coimbatore, India. **Date of publication:** 26 May 2016 (online & print)

Manuscript details: Ms # 2276 | Received 05 September 2015 | Final received 01 April 2016 | Finally accepted 09 May 2016

Citation: Raju, A.J.S. & R. Kumar (2016). Pollination ecology of *Derris trifoliata* (Fabaceae), a mangrove associate in Coringa Mangrove Forest, Andhra Pradesh, India. *Journal of Threatened Taxa* 8(5): 8788–8796; http://dx.doi.org/10.11609/jott.2277.8.5.8788-8796

Funding: Self-funded.

Conflict of Interest: The authors declare no competing interests.

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Author Contribution: Both the authors contributed to a similar extent overall.

Acknowledgements: We thank the Andhra University, Visakhapatnam for providing us facilities to carry out this work.

INTRODUCTION

The focus of research on the reproductive biology of mangrove plants has almost exclusively been on the fruit, seed or seedling dispersal stage. Surprisingly, less is known about the floral biology, pollination, and breeding systems although knowledge of the effectiveness of floral mechanics and genetic isolating mechanisms is an important pre-requisite to the study of successful dispersal and establishment (Primack et al. 1981; Tomlinson 1986; Juncosa & Tomlinson 1987; Clarke & Meyerscough 1991; Azuma et al. 2002; Ge et al. 2003; Chiou-Rong et al. 2005; Coupland et al. 2006). In India, a few studies provide some preliminary accounts of floral biology and pollination in some mangrove plants (Raju 1990; Raju et al. 1994, 2006; Reddi & Raju 1997; Raju & Jonathan 2008; Jonathan & Raju 2009; Pandit & Choudhury 2001; Jonathan 2009; Mohan 2009). The available information relates to viviparous and crypto-viviparous species but not to non-viviparous true mangroves or mangrove associate species.

The present study is an attempt to provide information on the ecological aspects of pollination in the mangrove associate species, *Derris trifoliata* Lour. (Fabaceae), occurring in the Godavari-Coringa mangrove forest in the state of Andhra Pradesh, India. It has a coastal distribution from East Africa, Madagascar, and throughout tropical and subtropical Asia to tropical Australia. It is recorded in coastal communities such as beaches, sand vegetation, and coastal swamps and is a frequent constituent of back mangal (inland portion of mangrove swamp) throughout its range (Tomlinson 1986). There is absolutely no information on its reproductive ecology despite its importance in stabilizing the estuarine soil as a creekside species. The information presented in this paper is useful to understand floral biology, sexual system, breeding systems and the factors contributing to the working of pollination mechanism by insects, especially by bees due to which fruit set and seed dispersal events occur.

MATERIALS AND METHODS

Study area

The Godavari mangrove wetland lies between 16^{0}30'–17^{0}00'N and 82^{0}10'–80^{0}23'E in the state of Andhra Pradesh, India. In this wetland, *D. trifoliata* grows here and there as small patches along the creeks. The plant is characteristically deciduous during the dry season, displays leaf flushing, flowering, fruiting, seed dispersal and seed germination during the wet season. Field studies and lab-works were made during the period from February 2011 to June 2014.

Flowering and floral biology

The flowering season was defined based on regular field trips made for three years. Observations regarding the organization of inflorescences, the spatial positioning of flowers, and their position (terminal, axillary, etc.,) on the plants were made since these features are regarded as important for foraging and effecting pollination by flower-visitors. The flower life was recorded by marking 25 just anthesed flowers and following them until fall off. Anthesis was initially recorded by observing 25 marked mature buds in the field. Later, the observations were repeated five times on different days in order to provide accurate anthesis schedule. Similarly, the mature buds were followed for recording the time of anther dehiscence. The presentation pattern of pollen was also investigated by recording how anthers dehisced and confirmed by observing the anthers under a 10x hand lens. The details of flower morphology such as flower sex, shape, size, colour, odour, tepals, stamens and ovary were described based on 25 flowers randomly collected from the population. The order of wilting or dropping off of floral parts was recorded. Observations regarding the position and spatial relationships of stamens and stigma in mature bud, at anthesis and after, during the flower-life with reference to self and/or cross-pollination were made very carefully.

Determination of pollen output

Twenty-five mature but undehisced anthers from five different plants were collected and placed in a Petri dish. Later, each time a single anther was taken out and placed on a clean microscope slide (75 x 25 mm) and dabbed with a needle in a drop of lactophenol-aniline-blue. The anther tissue was then observed under the microscope for pollen, if any, and if pollen grains were not there, the tissue was removed from the slide. The pollen mass was drawn into a band, and the total number of pollen grains was counted under a compound microscope (40x objective, 10x eye piece). This procedure was followed for counting the number of pollen grains in each anther collected. Based on these counts, the mean number of pollen produced per anther was determined. The mean pollen output per anther was multiplied by the number of anthers in the flower for obtaining the mean number of pollen grains per flower. The characteristics of pollen grains were also recorded.

Determination of pollen-ovule ratio: The pollen-

ovule ratio was determined by dividing the average number of pollen grains per flower by the number of ovules per flower. The value thus obtained was taken as pollen-ovule ratio (Cruden 1977).

Examination of nectar characters: The presence of nectar was determined by observing the mature buds and open flowers. The volume of nectar from 10 flowers of each plant species was determined. Then, the average volume of nectar per flower was determined and expressed in µl. The flowers used for this purpose were bagged at mature bud stage, opened after anthesis and squeezed nectar into a micropipette for measuring the volume of nectar. Nectar sugar concentration was determined using a Hand Sugar Refractometer (Erma, Japan). Ten samples were used for examining the range of sugar concentration in the nectar. For the analysis of sugar types, paper chromatography method described by Harborne (1973) was followed. Nectar was placed on Whatman No. 1 of filter paper along with standard samples of glucose, fructose and sucrose. The paper was run ascendingly for 24 hours with a solvent system of n-butanol-acetone-water (4:5:1), sprayed with aniline oxalate spray reagent and dried at 120^{0}C in an electric oven for 20 minutes for the development of spots from the nectar and the standard sugars. Then, the sugar types present and also the most dominant sugar type were recorded based on the area and colour intensity of the spot. The sugar content/flower is expressed as the product of nectar volume and sugar concentration per unit volume, mg/µl. This is done by first noting the conversion value for the recorded sugar concentration on the refractometer scale and then by multiplying it with the volume of nectar/flower. Table 5.6 given in Dafni et al. (2005) was followed for recording the conversion value to mg of sugars present in one µl of nectar.

Determination of stigma receptivity: The stigma receptivity was observed visually and by H_2O_2 test. In visual method, the stigma physical state (wet or dry) and the unfolding of its lobes were considered to record the commencement of receptivity; withering of the lobes was taken as loss of receptivity. H_2O_2 test as given in Dafni et al. (2005) was followed for noting stigma receptivity period. This test is widely followed although it does not indicate the exact location of the receptive area. In the present study, the period of slow release of bubbles from the surface of stigma following the application of hydrogen peroxide was taken as stigma receptivity.

Assessment of Breeding Systems and fruiting behavior: Mature flower buds of some inflorescences on different individuals were tagged and enclosed in finemesh bags. They were tested in the following way and the number of flower buds used for each mode of pollination was given in Table 1.

1. The inflorescences with known number of flowers were tagged and followed for fruit set in open-pollination mode.
2. The flowers were fine-mesh bagged without hand pollination to observe fruit set in autonomous autogamy.
3. The emasculated flowers were left un-bagged and followed for fruit set in insect-assisted pollination.

The percentage of fruit set in each mode was calculated based on the number of flowers set fruit against the number of flowers tagged/bagged. Fruit maturation period, fruit dehiscence and seed dispersal aspects were observed to the extent possible.

Observations of flower-visitors: After making preliminary observations on flower visitors, a thorough knowledge of the local insect species was obtained by observing the representative species of insects available with the Pollination Ecology Laboratory in the Department of Environmental Sciences, Andhra University, Visakhapatnam. With the knowledge of local insect species, attempts were made to observe flower visitors. The hourly foraging visits of each insect species were recorded on 3 or 4 occasions depending on the possibility and the data was tabulated to use the same for further analysis. Fully blooming plants were selected to record the foraging visits of insects. The data obtained was used to calculate the percentage of foraging visits made by each insect species per day and also to calculate the percentage of foraging visits of each category of insects per day in order to understand the relative importance of each insect species or category

Table 1. Results of breeding experiments on *Derris trifoliata*

Test	Treatment	Pollen source	No. of flowers/plants	Fruit set (%)
Control	Un-bagged	Open pollination	250/25	28.8
Autonomous autogamy	Fine-mesh Bagged	Within flower	150/10	2.66
Insect-assisted cross-pollination	Un-bagged, Emasculated	Other flowers on the same or different plants	200/25	31

of insects.

Determination of pollen carryover efficiency of insects: The flower visitors captured during 1000–1200 hr were brought to the laboratory. For each insect species, 10 specimens were captured and each specimen was washed first in ethyl alcohol and the contents stained with aniline-blue on a glass slide and observed under microscope to count the number of pollen grains present. From this, the average number of pollen grains carried by each insect species was calculated to know the pollen carryover efficiency of different insect species.

Determination of foraging behaviour of insects: The foraging behaviour of insect species was observed on a number of occasions for the mode of approach, landing, probing behaviour, the type of forage collected, contact with essential organs to result in pollination, inter-plant foraging activity in terms of cross-pollination, etc.

Photography: Study area, habitat, plant, flower and fruit details together with insect foraging activity on the flowers were photographed with a Nikon D40X Digital SLR (10.1 pixel) and TZ240 Stereo Zoom Microscope with SP-350 Olympus Digital Camera (8.1 pixel). Olympus Binoculars (PX35 DPSR Model) was also used to make field observations. Magnus Compound Microscope - 5x, 10x, 40x and 100x magnification was used for studying the pollen characteristics.

RESULTS

Phenology

Derris trifoliata is a deciduous woody climber with pinnate leaves, growing to a length of up to 15m (Image 1a). The stem is covered with a smooth, dark brown, corky bark with orange lenticels. The young stems are dark red, strongly ridged and have prominent lenticels. The flowering occurs from the 1st week of July to the 1st week of August. It exhibits massive blooming. An individual flowers for about 1–2 weeks. The inflorescence is a raceme of 112±3 mm length (Range 50–160) which is borne in the axils of stems growing horizontally, along the ground. An inflorescence produces 56.03 ± 33.19 (Range 15–182) flowers over a period of 2–3 days in an acropetal manner (Image 1b). The flowers are arranged horizontally to the inflorescence axis.

Flower morphology

Flowers are pedicellate, small, 10mm long, pinkish white, odourless, delicate, papilionaceous, bisexual and zygomorphic. Sepals are 5, slightly fused at base forming a shallow cup, 2mm long, light green, and glabrous. Petals are 5, one pinkish white 10mm long standard petal, two light pink 5mm long wing petals and two white 5mm long keel petals. The standard petal is broad with a light greenish-white nectar guide at the center and hook-like structures at the base; it is posterior in position and encloses the margins of wing petals, which in turn overlap the margins of keel petals. The keel petals represent a boat-shaped structure in which the stamens and stigma are embedded. Stamens are 10, diadelphous with nine stamens united into one bundle while the tenth one is free. The bundled stamens form a staminal tube at the base and the filaments become free towards the apex and bear monomorphic, dithecous basifixed anthers. All the ten stamens have a common origin at the flower base; their filaments are whitish green, slender and delicate. The bundled stamens bend inward and form a conical-shaped tube at the extreme flower base, while the tenth stamen arises separately without any bending and forms open gaps on both sides towards the staminal tube (Image 1e,f). The tenth stamen is quite opposite to the standard petal. All the ten stamens have prominent upward arching. The ovary is semi-inferior with a single carpel having six light green and shiny ovules arranged in a linear manner on marginal placentation (Image 1j). It has a light green style terminated with a wet, light yellow capitate stigma; the terminal portion arches upwards (Image 1i) and extends 2 mm beyond the height of the anthers (Image 1g).

Floral Biology

The mature buds open during 0600–1100 hr with peak anthesis at 0800hr (Image 1c). Unfolding of the standard petal indicates flower opening (Image 1d). The wing and keel petals do not unfold and remain in their original position as in mature bud stage but in tensed state. All the ten anthers dehisce by longitudinal slits in mature bud stage (Image 1h). The number of pollen grains per anther is 1123.9 ± 96.76 (Range 1020–1303) and per flower is 11,239. Pollen grains are granular, triangular, smooth exine, tricolporate at equal distance and 41.5µm in size. The pollen-ovule ratio is 1873:1. The pollen protein content per anther is 0.6µg and per flower is 6µg. The stigma attains receptivity one hour after anther dehiscence and continues until the standard petal closes back; but strong receptivity occurs during 0900–1500 hr. Nectar secretion begins inside the staminal tube at the base an hour after anthesis. Its secretion is continuous for 5 hours during flower-life. The total amount of nectar produced per flower is 1.50 ± 0.2 (Range 1.2-1.9) µl. The nectar sugars included sucrose, glucose and fructose with the first as dominant

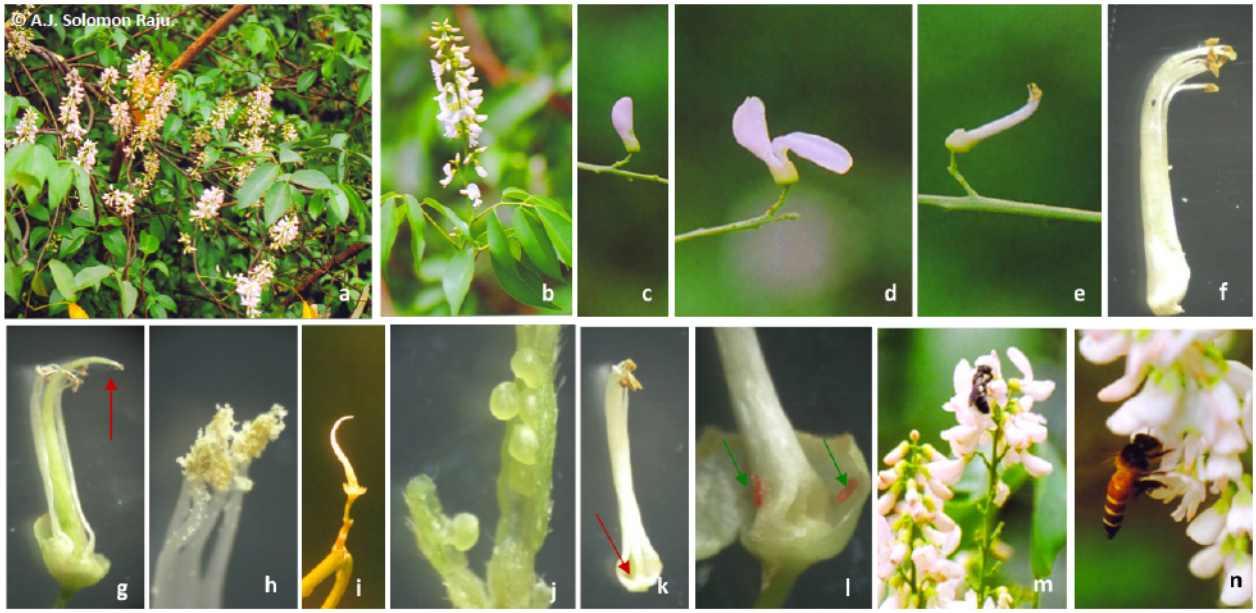

Image 1. ***Derris trifoliata*****: a - Flowering climber; b - Flowering inflorescence; c - Mature bud; d - Flower; e - & f - Stamens; g - Extension of curved part of style and stigma beyond anthers; h - Dehisced anthers; I - Ovary with curved style and stigma.; j - Linear arrangement of ovules; k - Exposure of nectar through openings between adjacent filaments; l - Red coloured thrips feeding on nectar; m - Unidentified bee probing for nectar collection; n -** ***Apis dorsata*** **probing for nectar collection.**

and sugar concentration varies from 21 to 32% (24.5 ± 5.3 %) through the day. The total nectar sugar content per flower is 0.43mg. Nectar is concealed by the hook-like structures of the standard petal, which hold the basal part of the wing and keel petals intact. It gets exposed through openings between adjacent filaments towards the side of the standard petal when the wing and keel petals are depressed by the forager (Image 1k). The flowers begin to close slowly from 1600hr onwards and close completely at 1800hr. Gradual movement of the standard petal to enclose the wing and keel petals completely indicates closure of the flower. The closed flowers remain so permanently and look similar to mature buds. In pollinated flowers, the petals fall off on the third day, staminal tube after 7 days and sepals after 10 days. The ovary gradually enlarges and grows into a fruit. Unpollinated flowers fall off on the 2nd day.

Breeding Systems

Floral bud abortion is 6% (Fig. 1). The results of breeding systems indicate that the flowers are self-compatible and self-pollinating. The fruit set is 2.66% in spontaneous autogamy, 31% in insect-assisted pollination and 28.8% in open pollination (Table 1). Of the fruit set in open pollination, 2% of fruits abort without reaching maturity (Fig. 1). Fruit set per inflorescence in open pollination is 9.52 ± 5.72 (Range 1–30).

Foraging activity and pollination

The flowers are specialized in that the stamens, style and stigma are in a tensed state and concealed in keel and wing petals even after the unfolding of the standard petal. They were foraged by bees and a butterfly throughout the day from 0600 to 1700 h for pollen and/or nectar (Table 2). The foraging activity was mainly concentrated around noon time only (Fig. 2). The foragers were bees such as *Apis dorsata* (Image 1n), *A. cerana, A. florea* (Image 2a-d), *Ceratina simillima,*, *Nomia* sp., *Megachile* sp. (Image 2e,f), *Pithitis binghami, Xylocopa latipes*, *X. pubescens*, *Xylocopa* sp. (Image 2g) and an unidentified bee (Image 1m); and the butterfly, *Catopsilia pyranthe* (Image 2h). The percentage of foraging visits varied with each forager species. *Megachile* and *Pithitis* bees made 56.2% of the total visits of foragers while the other forager species made 2 to 8.5% of visits (Figure 3). All forager species probed the flowers from the front side without any side-working. *Xylocopa* bees and the butterfly collected only nectar while all other bees collected both pollen and nectar. Bees on landing, depressed the wing and keel petals and reached the nectar area for nectar collection, then the stamens and stigma were released violently from the keel petals. Simultaneously, the stigma and pollen ejected explosively from the anthers and become stuck to the ventral side of these bees. The

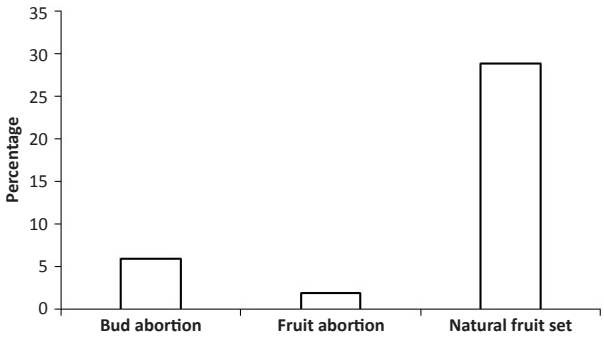

Figure 1. Bud, fruit abortion and natural fruit set rate in *Derris trifoliata*

bees such as *Apis, Megachile, Pithitis* and *Xylocopa* were highly efficient in depressing the keel petals to access the nectar. The other bees were relatively inefficient in tripping the keel petals but they appeared to be successful mostly with previously visited flowers. To collect pollen, the bees during the same or consecutive visits, gradually turned their heads away from the standard petal and moved towards the location of the anthers and stigma. In doing so, they invariably contacted the stigma, effecting pollination. With the departure of these bees, the keel and wing petals returned to their original state concealing the nectar, stamens and stigma. All the bees were found to collect forage from each flower very fast and in quest of more forage, they quickly moved between inflorescences on the same or different individual plants, contributing to self- and cross-pollination. Further, they also carried more pollen on their ventral side and pollen collecting bees stored pollen in their pollen baskets (Table 3). The lone butterfly, *C. pyranthe* landed on the flower and inserted its proboscis slowly into the nectar location by the side of the standard petal to collect nectar. It was unable to trip the keel petals to cause pollination but it could effect pollination in the tripped flowers which received multiple visits by bees. Its proboscis was found with an average number of 91 ± 21.0 pollen grains (Table 3). Of the foragers, *Megachile* and *Pithitis* bees were consistent foragers while all the other foragers were relatively inconsistent during the entire flowering period. Red coloured thrips were found to breed in buds (Image 1l); when mature buds open, they move within and between inflorescences for collecting more nectar and pollen. In some flowers, numerous thrips were found and they exhausted all the secreted nectar making it unavailable for the appropriate foragers. Thrips were found to have a little role in pollination. Thrips feeding activity appeared to compel the bees to pay visits to a number of flowers in order to get the required quantity of forage for them.

Table 2. List of insect foragers on *Derris trifoliata*

Order / Family	Insect species	Common name	Forage sought
Hymenoptera			
Apidae	*Apis dorsata*	Rock Bee	Pollen + Nectar
	Apis cerana	Asiatic Hive Bee	Pollen + Nectar
	Apis florea	Dwarf Honey Bee	Pollen + Nectar
Anthophoridae	*Xylocopa latipes*	Carpenter Bee	Nectar
	Xylocopa pubescens	Carpenter Bee	Nectar
	Xylocopa sp.	Carpenter Bee	Nectar
	Ceratina simillima	Small Carpenter Bee	Pollen + Nectar
	Pithitis binghami	Green Bee	Pollen + Nectar
	Anthophora bicincta	Blue Banded Bee	Pollen + Nectar
Halictidae	*Nomia* sp.	--	Pollen + Nectar
Megachilidae	*Megachile* sp.	Leaf Cutter Bee	Pollen + Nectar
	Unidentified Bee	--	Pollen + Nectar
Lepidoptera			
Pieridae	*Catopsilia pyranthe*	Mottled Emigrant	Nectar

Table 3. Pollen carrying capacity of insect foragers on *Derris trifoliata*

Insect species	Sample size	Range	Mean ± S.D.
Apis dorsata	10	525–989	736.1±141.4
A. cerana	10	306–810	562.2±171.9
A. florea	10	329–781	574.4±147.3
Ceratina simillima	10	124–321	232.3±71.0
Nomia sp.	10	76–156	121.3±27.4
Megachile sp.	10	295–864	508.2±197.0
Pithitis binghami	10	356–835	599.6±190.2
Xylocopa latipes	10	716–1043	888 ±102.7
X. pubescens	10	674–1176	913.1±168.3
Xylocopa sp.	10	560–910	710.6±129.8
Catopsilia pyranthe	10	86–132	91±21.0

Fruiting behaviour

Pollinated and fertilized flowers initiate fruit development immediately and take about a month to produce mature fruits (Image 2i,j). Fruit is 1-3 seeded flat, oval, leathery and slightly wrinkled pod; it is 30–40 mm long and 20 mm across, green at first, turning light brown when ripe. Air cavities were present between the

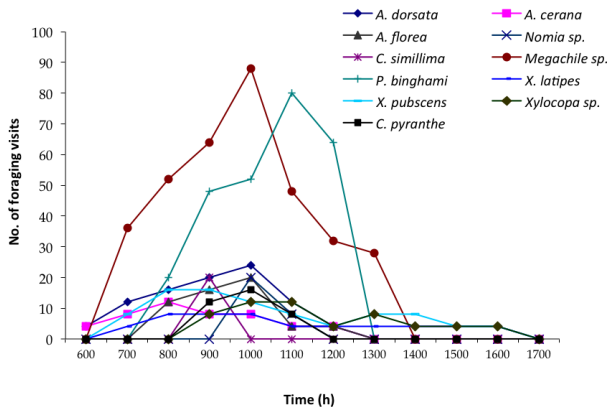

Figure 2. Hourly foraging activity of insects on *Derris trifoliata*

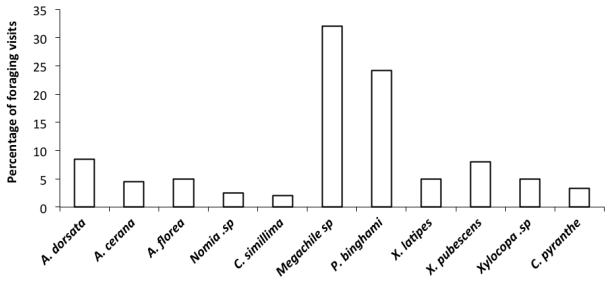

Figure 3. Percentage of foraging visits of insects on *Derris trifoliata*

pod and seed and these cavities assist in buoyancy when the fruit falls from the plant into the water. The leathery pod breaks open exposing the seed by absorbing water. Both the pod and seeds float in water and disperse to different distances depending on tidal flow and direction. During the low tide period, the forest floor is exposed and if the pods/seeds fall at that time they settle right at the mother plant, then the pods break and seeds germinate to produce new plants.

DISCUSSION

The plant is a deciduous woody climber distributed from oligohaline to polyhaline zones in the mangroves. It displays massive flowering for about a month during the rainy season. The acropetal anthesis and the flowers borne in nearly erect racemose inflorescences are quite distinct against the foliage. The floral characteristics such as small size, pinkish white papilionaceous corolla with explosive pollen release mechanism and zygomorphic symmetry indicate that the plant has a specialized pollination mechanism adapted for tripping by external agents. Such an explosive pollination mechanism has also been reported in the allied species, *Pongamia pinnata* (Raju & Rao 2006), other Fabaceae members (Meeuse 1961) and also in other plant families such as Lamiaceae (Raju 1990), Loranthaceae (Feehan 1985), Onagraceae (Plitmann et al. 1973), Rhizophoraceae (Davey 1975; Tomlinson et al. 1979), Marantaceae (Davis 1987), Urticaceae (Taylor 1942), Ericaceae (Marie-Victorin 1942), Fumariaceae, Musaceae, Acanthaceae (Proctor & Yeo 1972), Cornaceae (Mosquin 1985) and Orchidaceae (Proctor & Yeo 1972; Gottsberger 1989).

In *D. trifoliata*, the forenoon anthesis and pollen and nectar as rewards attract daytime foragers. The nectar feeding foragers require strength to depress the keel petals in order to collect nectar; only those foragers which have the required strength to do so can collect nectar and in the process trip the floral mechanism and effect pollination. When floral explosion occurs, pollen is somewhat exposed and the pollen feeding foragers then collect it. The small volume of sucrose-dominant nectar with high sugar concentration in the flowers of *D. trifoliata* is an adaptation for pollination by long-tongued bees (Baker & Baker 1983). But, the present study showed that both long- and short-tongued bees trip the flowers, collect nectar and effect pollination. *Ceratina* and *Nomia* bees are comparatively less efficient than other bees in tripping the flowers and effecting pollination. The butterfly, *Catopsilia pyranthe* also feeds on this floral nectar and plays a minor role in pollination. The floral nectar of *D. trifoliata* may also provide a few or some essential and non-essential amino acids for the bees and the butterfly; but nectar analysis for these chemicals is suggested to confirm this. The flowers produce pollen in moderate amount and it has a small amount of protein. The pollen grains being small in size and with tricolporate exine structure adhere in clumps and hence are easy for bees, especially honey bees to collect and keep them in their pollen baskets (Lakshmi et al. 1997). All the bees except *Xylocopa* bees collect pollen from the dehisced anthers which are situated in the keel petals and invariably contact and pollinate the stigma. The specialized explosive floral mechanism is no doubt an important floral adaptation to discourage self-pollination and promote cross-pollination. The flowers close at the end of the day and remain so until they fall off; such a flower function may allow re-mobilization and recycling of structural proteins and nutrients from the flowers back to the plant and serve as an energy-efficient means of enhancing the overall attractiveness of the inflorescences or plant to pollinators (Gori 1983). Therefore, the pollination system in *D. trifoliata* essentially requires insect pollinators as in *Pongamia*

Image 2. *Derris trifoliata* - a–h: Flower foragers: a–c - *Apis florea* collecting pollen in different positions; d - *A. florea* collecting nectar; e & f - *Megachile* sp. probing for nectar collection; g - *Xylocopa* sp. collecting nectar; h - *Catopsilia pyranthe* probing for nectar collection; I & j - Fruit set in open pollinations.

pinnata (Raju & Rao 2006). Thrips use the flower buds of *D. trifoliata* for breeding and move out when the buds are open. They exhaust the nectar resource in some flowers and in effect compel insect pollinators to make multiple visits to the same or different plants in search of nectar. Such a foraging behaviour would be advantageous for the plant to maximize cross-pollination in the presence of insect pollinators.

D. trifoliata is weakly protandrous, self-compatible and self-pollinating. In the keel petals, the stigma slightly exceeds the length of the stamens and contacts the underside of pollinator's body first when the latter visits the flower in quest of nectar and/or pollen. Such a position of stigma appears to be an adaptation for promoting cross-pollination. The pollen-ovule ratio of the plant also favours cross-pollination (Cruden 1977). Individual flowers that were not tripped by insects set fruit and hence it is an indication of autogamy; but fruit set in this mode of pollination is negligible and it is a function of the stigma gaining contact with the dehisced anthers within the intact keel petals. In insect-assisted and open-pollination modes, fruit set rate is only up to 30–31% despite the flowers being visited by insect pollinators. This low natural fruit set rate could be primarily due to a scarcity of nutrient resources available to the plant. Flower bud abortion is at significant level which may additionally indicate the nutrient status of the plant. Similar situation exists also in the related species, *P. pinnata* (Raju & Rao 2006). Therefore, *D. trifoliata* with a mixed mating system is able to set fruit through self- and cross-pollination; the genetic variation resulting from outcrossing enables it to survive well and colonize the mangrove areas to the extent possible.

Fruits of *D. trifoliata* mature quickly in a month. Each fruit contains 1–3 seeds against 6 linearly arranged ovules in the ovary. The regulation of seed set within the fruit may be a character of the plant or due to the scarcity of nutrient resources. Fruits do not dehisce and seeds also do not germinate while on the parent plant. The fruits are leathery and possess air cavities, the characteristics of which enable them to float in tidal water. They settle at the parent plant if the site is partly or fully exposed or float to be dispersed if the site is inundated with tidal water. It suggests that the plant uses both self-planting and stranding strategies for dispersal and establishment. Seed release occurs when fruits absorb water and the pericarp breaks. Seeds germinate only when they reach a suitable habitat in mangroves. The importance or significance of this work cannot be highlighted in the absence of information on other species of *Derris* or other genera of Fabaceae inhabiting the mangroves.

CONCLUSION

Derris trifoliata is a lesser known species in the mangrove ecosystem. Its occurrence at ground level and climbing habit is important for covering and stabilizing the banks of creeks of brackish water. This species with a mixed breeding system and explosive pollination mechanism is adapted for pollination by insects, especially bees. Un-tripped flowers do not set fruit. The fruits possess special characteristics that enable them to float in tidal water and eventually to settle in favorable sites where seeds germinate and produce new plants. This species with its profuse flowering provide ample forage for insects, especially bees. Therefore, the interactions between *D. trifoliata* and insects are mutualistic, the former for pollination and the latter for food.

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