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# POLLINATION ECOLOGY OF THE RARE TROPICAL DECIDUOUS TREE SPECIES, *MAERUA APETALA* (ROTH) M. JACOBS (CAPPARACEAE) IN THE SOUTHERN EASTERN GHATS FOREST OF ANDHRA PRADESH, INDIA

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Abstract - *Maerua apetala* (Roth) M. Jacobs is a rare tropical deciduous tree species. Leaf fall and leaf flushing occur almost simultaneously during late December-mid-February while flowering occurs during March-April. The flowers are white with a creamy tinge, hermaphroditic, strongly protandrous and obligately xenogamous. The floral characters such as morning anthesis, anther dehiscence immediately after anthesis, large size, scent production, numerous exerted stamens, sufficient volume of nectar and huge pollen production suggest a mix of entomophily and zoophily. Accordingly, the tree is pollinated by bees and birds; the former promotes geitonogamy while the latter promotes xenogamy. Among birds, sunbirds are typically nectar robbers while other birds are pollinators. Fruit dispersal mode is barochory but seed germination and seedling formation either at parental trees or away from them have not been found and hence the tree is on the verge of extirpation.

Keywords: *Maerua apetala*; protandry; obligate xenogamy; entomophily; zoophily; barochory.

## Introduction

The genus *Maerua* belongs to the sub-family Capparoideae. It is a large polymorphous genus with 90 species, primarily African in distribution with a few species distributed in tropical Asia, India and Madagascar (De Wolf, 1962, Chayamarit, 1991, Nobsathian et al., 2018). But, details of taxonomic descriptions of this genus are not adequately available. *Maerua* species have been used as food in the areas of its distribution, especially in Africa (Cook et al., 1998). *M. crassifolia* Forssk. is a common nutrition source in central Africa (Spittler, 1983) and its leaves are used as fodder for animals, especially for camels during the dry season in parts of Africa (Miller & Cope, 1996). Further, its leaves are recommended as a nutritious leafy vegetable for consumption by populations inhabiting the transition zone between Sahara desert in North Africa and the Sudanian savannas in the South (Cook et al., 1998). *M. subcordata* (Gilg) DeWolf produces tuberous roots and they are used in traditional medicine in the dry parts of East Africa (Kers, 2000, Hiben et al., 2019). Different species of *Maerua* are used in the treatment of intestinal diseases, mental illness, diarrhea, epilepsy and vomiting (Chhabra and Uiso, 1990).
Salewski et al. (2006) reported that migrant birds, *Hippolais pallida* Hemprich & Ehrenberg, *H. opaca* Cabanis, *Sylvia hortensis* Gmelin, *S. communis* Latham, *S. cantillans* Pallas, *Phylloscopus collybita* Vieillot and *P. trochilus* Vieillot use the oasis of Ouadane as a stopover site in the western Sahara, Mauritiana. At this site, they use *Maerua crassifolia* Forssk. along with other tree species as a nectar source as water is least available in the dry environment of Ouadane. These birds are important for *M. crassifolia* Forssk. for pollination during day time and the hawk moth, *Hyles lineata* F. acts as pollinator after sunset while collecting nectar. In Oman, *M. crassifolia* Forssk. is a major pollen plant for honey bees during the spring season (Sajwani et al., 2014; Abou-Shhaara, 2019). However, *Maerua* genus has not been thoroughly investigated for its

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pollination ecology in any part of its distribution, despite its value in traditional medicine, food and ecology of the habitat of its occurrence.

*Maerua* species distributed in India have not been well documented. But, the literature scan indicates that three species of *Maerua* occur here, viz. *M. arenaria* Hook.f. & Thomas, *M. oblongifolia* (Forsk.) A. Rich and *M. apetala* (Roth) M. Jacobs; the first species is reported to be occurring in the Delhi area (Mishra et al., 2015) while the other two species occurring in the Eastern Ghats of India (Pullaiah & Muralidhara Rao, 2002). *M. apetala* (Roth) M. Jacobs is a deciduous tree species and endemic to India while *M. oblongifolia* (Forsk.) A. Rich is common in semi-arid and scrub jungles of Eastern Ghats (Pullaiah & Muralidhara Rao, 2002). *M. apetala* (Roth) M. Jacobs is used in traditional medicine. Root extract is used orally to treat leucoderma while the leaf paste mixed with spices made into pills is used orally for nervous disorders and foot pain by Chenchu and Lambadi tribes (Pullaiah, 2000). None of these species have been investigated for their pollination ecology so far. Therefore, the present study is contemplated to provide information on the pollination ecology of *M. apetala* (Roth) M. Jacobs due to its endemic status to understand the factors that make this tree species to be endemic or rare.

## Materials and Methods

### Study area

*Maerua apetala* is a small to medium-sized deciduous tree species distributed sparsely in the open tropical deciduous reserve forest of southern Eastern Ghats at Idupulapaya (Latitude 14°19.418 N, Longitude 78°31.468 E and 280 m asl) in Kadapa District, Andhra Pradesh, India (Figure 1a, b). In this reserve forest, the terrain is rocky, rugged and soil deficient in nutrients. Deciduous tree species *Cochlospermum religiosum* L. (Alston) (Cochlospermaceae), *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f., *Croton scabiosus* Bedd. (Euphorbiaceae), *Gardenia latifolia* Ait. (Rubiaceae) along with *Maerua apetala* (Roth) M. Jacobs (Capparaceae) appear here prominently during the dry season. *M. apetala* (Roth) M. Jacobs is represented by a population of only 14 trees in this forest indicating that it is a rare species. In this area, the annual average temperature is 29.2 °C with the temperature reaching up to 47 °C during dry season from March-May while the annual average precipitation is 753 mm. Since the study area is a part of Reserve Forest under the jurisdiction of the Government of Andhra Pradesh, field visits and study period were restricted by the Forest Department, and within the permitted period, the study was conducted during 2018 and 2019. Before making field observations and collecting the data, field visits were made to the Idupulapaya Reserve Forest to have an idea of leaf flushing and flowering time to proceed with the work.

### Floral biology

Anthesis and anther dehiscence events were recorded by observing twenty marked mature buds on the tree. The presentation pattern of pollen was also recorded by observing how anthers dehisced and then confirmed by using a 10x hand lens. Flower details such as flower sex, shape, size, color, odor, sepals, stamens, and ovary were recorded. The nectar was measured with a micropipette; the latter was inserted into the calyx cup to extract nectar for measurement. The average volume of nectar from ten flowers was taken as the total volume of nectar/flower and expressed in µl. The nectar from these flowers was used to record sugar concentration using Hand Sugar Refractometer (Erma, Japan). Pollen viability and stigma receptivity were tested according to the procedure described in Dafni et al. (2005).

### Breeding systems and open-pollination

Breeding systems were tested for apomixis, self-pollination and cross-pollination. The number of mature buds selected was 15 for each mode of pollination and followed for 45 days for the fruit set. Based on the flowers that produced fruits, the percentage of fruit set was calculated. Mature buds were emasculated and bagged to test apomixis. Mature buds were bagged without emasculation and pollination to test spontaneous self-pollination (autogamy). Mature buds were bagged on the evening of the previous day, opened on the 2$^{nd}$ day by which time anthesis, anther dehiscence and stigma receptivity occurred; the stigma was then pollinated with the pollen of the same flower using a brush and bagged to test hand self-pollination (autogamy). Mature buds were bagged after emasculation, opened on the 2$^{nd}$ day by which time the anthesis and stigma receptivity occurred; the stigma was pollinated with the fresh pollen of a different flower of the same tree using a brush and bagged to test hand self-pollination (geitonogamy). Mature buds were bagged after emasculation, opened on the 2$^{nd}$ day by which time the anthesis and stigma receptivity occurred; the stigma was then pollinated with the fresh pollen from the flower of a different tree using a brush and bagged to test hand cross-pollination (xenogamy). Forty flowers, four each from ten trees were tagged before anthesis and followed for fruit set. Based on the flowers that produced fruits, the percentage of fruit set was calculated.

### Airborne pollen and anemophily

Microscopic slides were coated with petroleum-jelly, fastened horizontally to the top of a 2 m long pole erected at four flowering trees and exposed to them to the air. The slides were

placed at 09:00 h and allowed them to the air until 11:00 h to trap the airborne pollen of the tree. The number of pollen grains per slide was counted for 1 $cm^2$ under the microscope. The pollen trapped by the slides belonged to *M. apetala* (Roth) M. Jacobs and *C. scabiosus* Bedd. but only the pollen of the former was counted.

**Flower-visitors and pollination**

Flowers were observed from morning to evening for four days to record the flower-visitors. The flower visitors included bees and birds only; the former were identified by Solomon Raju while the birds were identified with the help of Hand Book of Indian Birds by Ali (1979). The approach of flower visitors to flowering branches, flower-probing, forage collected by them and the contact between the body parts of flower visitors with the stigma and stamens were carefully observed by standing close to the flowering tree and also by using a field binocular to record their pollination role. The number of foraging visits made by flower visitors was recorded at each hour for ten minutes from morning to evening for four days at thirty profusely flowering branches. The data collected on the foraging visits of these insects were tabulated and the mean number of foraging visits at each hour was calculated to know the foraging pattern of insects through time and also to calculate the percentage of foraging visits made by bees and birds separately. Ten individuals of each bee species were collected at noontime, killed and brought to the laboratory. The pollen load in the corbiculae of honey bees was removed before their body washings for pollen. Carpenter bees did not have any special pollen load structures. Each bee specimen was thoroughly washed in glycerine with aniline-blue stain on a microscope slide and observed under the microscope for counting the number of pollen grains. After counting the pollen from all collected specimens, the range, mean and standard deviation of the pollen grains recovered from each bee species were recorded to evaluate their pollen carry-over efficiency.

**Fruiting ecology**

Thirty mature buds were tagged and followed for three months to record the fruit growth, development and maturation period. Fruit dehiscence mode and seed dispersal aspects were observed. Fruit and seed morphological characteristics were described to understand fruit/seed dispersal modes.

## Results

**Flowering**

*M. apetala* (Roth) M. Jacobs is a small to medium-sized deciduous tree species. The stem is erect with a few vertically held branches (Figure 1a). The bark is grey-colored, finely


**Figure 1.** *Maerua apetala:* (a) Trunk, (b) Tree in flowering phase (c, d) Twig with buds.

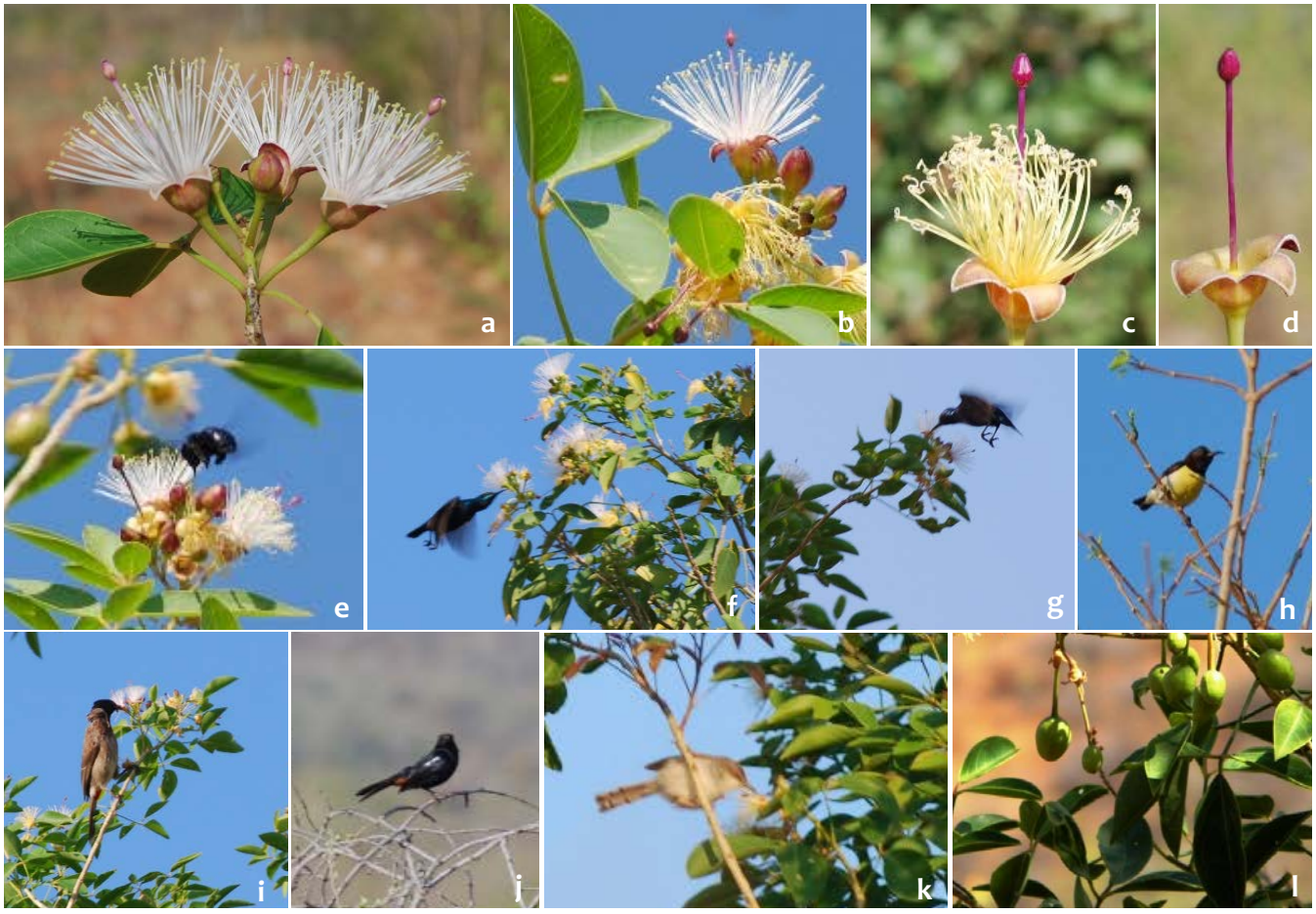


**Figure 2.** *Maerua apetala:* (a, b) Flowering inflorescences, (c) 2nd day flower, (d) Pistil, (e) *Xylocopa latipes* approaching the flower base to collect nectar, (f-l). Birds collecting nectar, (f, g) *Nectarinia asiatica* (male), (h) *Nectarinia zeylanica* (male), (i) *Pycnonotus cafer*, (j) *Saxicoloides fulicatus* (male) perching on the tree prior to nectar collection, (k) *Saxicoloides fulicatus* (female) collecting nectar, (l) Fruits from open-pollinations.

smooth with wrinkles and fissures. The leaves are petiolate, 3-5 foliate, arranged alternately; leaflets are linear-oblong, glabrous, thick and minutely wrinkled with an entire margin and acute apex. Leaf fall and flushing occur side by side between late December and mid-February. Leaf flushing is followed by the production of inflorescences and initiation of floral bud development. Flowering occurs during March-April (Figure 1b) and it is almost synchronous among different conspecific trees. The inflorescences are borne terminally at the end of branches and in the axils of leaves; they are corymbose racemes with 5-15 buds (Figure 1c,d). Individual racemes anthese within a week time to produce flowers (Figure 2a, b).

## Flower morphology

The flowers are pedicellate, large, 2.5-3 cm long, 3.5-4.5 cm across, white with a creamy tinge, fragrant, actinomorphic and hermaphroditic. The calyx is cup-shaped with four sepals which are fused at the base, brownish-green, and curved backward. The corolla is absent. The stamens are many, varying from 60 to 86 with varying lengths, exerted and spreading; all are inserted on the torus inside the basal part of the calyx. The staminal filaments are white while the anthers are creamy colored and dorsifixed. The ovary is at the end of 2.7-3.5 cm long erect and linear gynophore exceeding the height of the stamens; both ovary and gynophore are purple and appear quite prominent against the white stamens. The ovary is ovoid, 1-celled with many ovules and arranged on parietal placentation; the style is insignificant while the stigma is disc-shaped.

## Floral biology

Mature buds that are destined to open the next day begin to enlarge from the late evening of the previous day. They are open during early morning from 06:00 to 07:00 h. Anther dehiscence occurs just after flower-opening; the anthers in a flower dehisce almost synchronously by longitudinal slits

to expose the pollen grains. The pollen grains are monads, tricolporate, reticulate, 26 µm on equatorial axis, 21 µm on polar axis, sub-prolate on the equatorial shape and trilobate on polar shape; they are viable until the evening of the day of anthesis. The stamens begin to fade from the evening of the day of anthesis and turn dark creamy colored by the evening of the next day and slowly one by one or in groups fall off on the third day. On the day of anthesis, the gynophore is white with a purple tinge while the ovary is light purple with a whitish tinge and the stigma is not receptive. On the 2nd day of anthesis, the gynophore, ovary and stigma, all turn dark purple and shiny and appear quite distinct against the fading and the downward-facing stamens (Figure 2c, d). The stigma becomes receptive from the morning of the 2nd day of anthesis and remains so until the evening of the 3rd day. The nectar is produced in the calyx cup from the mature bud stage onwards and its secretion continues for about three hours after anthesis. Individuals flowers produce 4.5 ± 0.68 µl of nectar with 22-34% sugar concentration. Nectar is available in 1- to 3-day old flowers and its availability depends on the number of visits received by flowers from the foragers. The flowers that were not visited by foragers on day 1 had the nectar intact, and it was kept available for use by foragers that make visits on 2-day and 3-day old flowers. The calyx is persistent and protects the basal part of the gynophore in fertilized flowers to enable it to supply the nutrients required for the growth and development of the fruit and the seeds.

**Breeding system**

Hand-pollination tests showed that the flowers do not set fruit through apomixis. Fruit set occurs through geitonogamy and xenogamy only, it is 13% in geitonogamy and 87% in xenogamy. Seeds were ill-developed and subsequently aborted in geitonogamous fruits while seeds were well developed in xenogamous fruits. The fruit set is 27% in open-pollinations (Table 1). The results of hand-pollinations indicated that the plant is obligately xenogamous.

**Table 1.** Results of breeding systems in *Maerua apetala*.

| Treatment | Number of flowers sampled | Number of flowers set fruit | Fruit set (%) |
|---|---|---|---|
| Geitonogamy (Flowers hand-pollinated and bagged) | 15 | 2 | 13 |
| Xenogamy (Flowers hand-pollinated and bagged) | 15 | 13 | 87 |
| Open pollination (Flowers tagged) | 40 | 11 | 27 |

**Airborne pollen and anemophily**

Microscopic slides coated with petroleum jelly placed at 2 m height around the trees and exposed during 09:00-11:00 h for airborne pollen from flowering trees showed that the pollen is airborne but the pollen load is too small. The pollen was mixed with *Croton scabiosus* pollen but this pollen was not counted. The pollen load consisted of 32-57 pollen grains per $cm^2$. The occurrence of pollen of this tree in the air indicated that wind has a role in pollen dispersal. But, the scattered distribution of the trees mixed with other co-flowering tree species and the airborne pollen drying because of high ambient temperature due to dry season provided limited scope for pollen dispersal and the occurrence of anemophily.

**Foraging activity and pollination**

**Bee-pollination**: The fresh, 1-, 2, and 3-day old flowers were foraged invariably by honey bees comprising of *Apis dorsata* Fabricius and *A. cerana* Fabricius (Apidae) for both pollen and nectar, and by carpenter bees comprising *Xylocopa latipes* Drury (Figure 2e) and *X. pubescens* Spinola (Anthophoridae) mostly for nectar (Table 2).

All these bee species foraged consistently and regularly during day time from 08:00 to 17:00 h with maximum visits from 1100 to 1300 h; their foraging visits accounted for 37% of total foraging visits collectively made by bees and birds. *Apis* bees spent on each flower they visited more than 5-8 minutes while *Xylocopa* bees spent on each flower more than 4-8 seconds for forage collection. The long time stay by *Apis* bees on each flower was considered to be effecting more geitonogamous pollinations than xenogamous pollinations. *Apis* bees transferred the pollen collected by them to the pollen comb on their hind legs and then they combed, compacted and transferred to the corbicula on the outside surface of the tibia of the hind legs. Since each flower produces huge quantity of pollen from numerous anthers, these bees still had a considerable number of pollen grains on their bodies, especially on their ventral side even after loading the pollen collected by them into their corbiculae. *Xylocopa* bees did not display the pollen loading behavior exhibited by *Apis* bees. The mean pollen recorded on the bodies of these bees varied from 103.5 ± 29.02 to 231.8 ± 47.73; it was 231.8 ± 47.73 in *A. dorsata* Fabricius, 207.8 ± 52.71 in *A. cerana* Fabricius, 132.7 ± 41.38 in *X. latipes* Drury and 103.5 ± 29.02 in *X. pubescens* Spinola (Table 3).

The bees approached the flowers in an upright position, landed either on the top of the stamens or at the junction of calyx and basal part of stamens before probing the flowers for forage collection. The collection of both pollen and nectar in the same visit was very rare. When landed on the top of the stamens, they collected pollen from the anthers and while doing so they had contact with the stigma due to which they

**Table 2.** List of flower-foragers on *Maerua apetala*.

| Order | Family | Insect species | Common Name | Forage sought |
|---|---|---|---|---|
| Hymenoptera | Apidae | *Apis dorsata* F. | Rock honey bee | Pollen + Nectar |
| | | *Apis cerana* F. | Indian honey bee | Pollen + Nectar |
| | Anthophoridae | *Xylocopa latipes* L. | Carpenter bee | Nectar |
| | | *Xylocopa pubescens* L. | Carpenter bee | Nectar |
| Passeriformes | Nectariniidae | *Nectarinia asiatica* Latham. | Purple Sunbird | Nectar |
| | | *Nectarinia zeylanica* L. | Purple-rumped Sunbird | Nectar |
| | Pycnonotidae | *Pycnonotus cafer* L. | Red-vented Bulbul | Nectar |
| | Muscicapidae | *Saxicoloides fulicatus* L. | Indian Robin | Nectar |

**Table 3.** Pollen recorded in body washings of bees on *Maerua apetala*.

| Insect species | Sample size (N) | Number of pollen grains recorded | | |
|---|---|---|---|---|
| | | Range | Mean | S.D |
| *Apis dorsata* | 10 | 120-307 | 231.8 | 47.73 |
| *Apis cerana* | 10 | 94-268 | 207.8 | 52.71 |
| *Xylocopa latipes* | 10 | 67-209 | 132.7 | 41.38 |
| *Xylocopa pubescens* | 10 | 40-155 | 103.5 | 29.02 |

transferred pollen sternotribically and effected pollination but each visit did not lead to contact between the body of the bee and the stigma. Of the total visits that constituted the landing of the bee on the top of the stamens, only 45% of visits had the contact between the bee and the stigma affecting pollination. When landed at the calyx point, they directly inserted their tongue into the calyx cup to collect nectar and after nectar collection, they simply departed from the flower; in this mode of forage collection, there was no contact between the bee and the stigma and hence nectar collection activity by bees had no role in effecting pollination. However, while collecting nectar, the bees had contact ventrally (sternotribically) with the stigma of the adjacent flower of the same inflorescence effecting pollination but the occurrence of pollination in this way was found to be dependent on the posture of the probing bee about the position and proximity of the stigma of the adjacent flower(s) of the inflorescence.

**Bird-pollination**: The fresh, 1-, 2, and 3-day old flowers were foraged invariably by four species of birds, *Nectarinia asiatica* Latham (Figure 2f, g)*, N. zeylanica* L. (Figure 2h) (Nectariniidae), *Pycnonotus cafer* L. (Figure 2i) (Pycnonotidae) and *Saxicoloides fulicatus* L. (Figure 2j, k) (Muscicapidae) (Table 2), for nectar during day time from 07:00 to 17:00 h with maximum foraging activity during 09:00-15:00 h. Their foraging visits accounted for 63% of total foraging visits made collectively by bees and birds. *Nectarinia* species, after reaching the flowering branch, hovered always at the flowers, inserted their bill into the calyx cup and remained more or less motionless for a few seconds for collecting nectar. During nectar collection, the bill and/or forehead of these species had contact with the peripheral stamens of the flower being probed. Further, at the same time, the ventral side of the bill and/or forehead of these birds had contact with the stigma and stamens of the adjacent flowers of the same inflorescence rarely, indicating that *Nectarinia* species are principally nectar robbers and effect pollination occasionally. *P. cafer* L. and *S. fulicatus* L. approached the flowers, landed on the same or nearby flowering branch, inserted their bill into the calyx cup for nectar collection. During probing and nectar collection, the forehead of these species had contact with the stamens and stigma of the flower being probed, and the ventral side of the head with the stigma and stamens of an adjacent flower of the same inflorescence effecting pollination. All four species of birds hopped from flower to flower of the same or different inflorescences of the same tree and different conspecific trees effecting geitonogamous and xenogamous pollination. But, *Nectarinia* species were treated to be mostly nectar robbers while the other two bird species as important pollinators. Nevertheless, all these bird species actively searched for the nectar which was taken out deliberately from the calyx cup indicating that this tree species is an important nectar source during the dry season.

But, *Nectarinia* species also used *Gardenia latifolia* Ait. as a nectar source; they made punctures at the base of the corolla tube to collect nectar and hence they acted as nectar robbers but not as pollinators. The study found that bees and the birds (*P. cafer* L. and *S. fulicatus* L.) were important as pollinators while *Nectarinia* birds as nectar robbers rather than pollinators. But, the floral architecture and traits characterize melittophily but not ornithophily.

**Fruiting ecology and seed dispersal**

Fertilized flowers initiate fruit development immediately and continue development until maturation (Figure 2l). Individual fruits mature within two months. They are initially green and turn brown later. Fruit is a berry, glabrous, 1.5 cm long, 1-2 ridged, many-seeded, indehiscent and hanging on a drooping elongated gynophore. Each fruit contains several small seeds, 6 mm across, oblong-ellipsoid, embedded in scarlet fruit pulp. Mature pulpy fruits fall to the ground under parental trees, decompose and expose seeds which are then ready for germination provided the soil is sufficiently wet and enriched with nutrients. Fruit dispersal occurs during rainy season but fruits and seeds were not found at parental trees and hence seed germination and seedling establishment aspects were not observed.

## Discussion

*Maerua* is a polymorphous genus and is distributed in the tropical and subtropical areas of Africa and Asia including India but it is primarily African (De Wolf, 1962, Chayamarit, 1991, Nobsathian et al., 2018). In India, there are no reports to indicate how many *Maerua* species are distributed here. Mishra et al. (2015) reported that *M. arenaria* Hook.f. & Thoms. occurs in the Delhi area. Pullaiah & Muralidhara Rao (2002) reported that *M. oblongifolia* (Forssk.) A. Rich. and *M. apetala* (Roth) M. Jacobs occur in the semi-arid and scrub jungles of Eastern Ghats of India. Further, these authors stated that *M. oblongifolia* (Forssk.) A. Rich. is common while *M. apetala* (Roth) M. Jacobs is endemic with occasional distribution in the Eastern Ghats forests. The present study reports that *M. apetala* (Roth) M. Jacobs is rare in the tropical dry deciduous forests of the southern Eastern Ghats of India and agrees with Pullaiah and Muralidhara Rao (2002) that it is endemic and occasional in occurrence.
Pullaiah (2000) reported that *M. apetala* (Roth) M. Jacobs blooms and fruits during July-December period in Guntur district, a part of Eastern Ghats. Pullaiah & Muralidhara Rao (2002) reported that *M. apetala* (Roth) M. Jacobs blooms during February-June period in the Eastern Ghats forests. The present study reports that *M. apetala* (Roth) M. Jacobs flowers for two months during March-April during which individual trees flower almost synchronously although occur scattered in the tropical dry deciduous forest ecosystem of the southern Eastern Ghats of Andhra Pradesh. Since individual trees flower for a few weeks, corymbose racemes shorten their blooming period to produce flowers massively to attract flower-foragers in the dry season.
In *Maerua* genus, the taxonomic details of the species described by different authors indicate that the flowers are white, creamy white and greenish-white, and hermaphroditic (De Wolf, 1962, Pullaiah & Muralidhara Rao, 2002; Mishra et al., 2015, Nobsathian et al., 2018; Hyde et al., 2020). The present study reports that *M. apetala* (Roth) M. Jacobs flowers are white with a creamy tinge, hermaphroditic, partially self-compatible facilitating fruit set through geitonogamy only but self-incompatibility becomes functional during the post-fertilization phase by aborting the growing seeds. Therefore, *M. apetala* (Roth) M. Jacobs is obligately xenogamous and it is further substantiated by its strong protandry, long duration of stigma receptivity and rare occurrence in tropical dry deciduous forest ecosystems of India.
In literature, there is no information on the reproductive ecology of any species of *Maerua* despite their importance in the tropical deciduous forest ecosystems of Africa and Asia. Salewski et al. (2006) reported that *M. crassifolia* Forssk. with a considerable population blooms during the dry season in the oasis of Ouadane in the Western Sahara, Mauritiana. Several migrant bird species use this oasis as a stopover site and feed on the nectar of *M. crassifolia* Forssk. along with other tree species blooming simultaneously. These authors opined that *M. crassifolia* Forssk. may have evolved its flowering phenology to coincide with the migration period of these birds. But, this opinion raises the doubt that actual pollinators of this tree species are different. In Oman, *M. crassifolia* Forssk. has been reported to be a major bee plant by Sajwani et al. (2014) and a pollen plant for honey bees during spring season by Abou-Shhaara (2019) indicating that bees could be the actual pollinators. The present study reports that *M. apetala* (Roth) M. Jacobs is a deciduous tree species and blooms after leaf flushing during dry season. The morning anthesis and anther dehiscence occurring almost immediately after anthesis indicate that the flowers are adapted for foraging by diurnal foragers. Airborne pollen from *M. apetala* (Roth) M. Jacobs is in small amounts and also mixed with the pollen of *Croton scabiosus* Bedd. The liberated pollen does not reach the target since the trees are scattered and intermingled with other co-flowering tree species. Additionally, high ambient temperature dries up the pollen causing the latter to lose its viability soon. The floral traits such as large size, fragrance emission, numerous

exerted stamens and actinomorphic symmetry provide attraction and facilitate easy landing for foragers. The flowers with a good volume of nectar and huge pollen production provide sufficient forage for flower-foragers which included bees and birds. The nectar sugar concentration is ideal for both bees and birds. The pollen collection activity of bees and nectar collection activity of the birds, *Pycnonotus cafer* L. and *Saxicoloides fulicatus* L. effect both self- and cross-pollination. Among bees, honey bees promote more geitonogamous pollinations than xenogamous pollinations as they tend to spend more time on the same flower/plant while carpenter bees promote more xenogamous pollinations as they tend to fly very swiftly and spend little time at each flower/plant. *P. cafer* L. and *S. fulicatus* L. also contribute to more xenogamous pollinations as they hop from flower to flower of the same and/or different conspecific trees very swiftly. The sunbirds, *Nectarina* species are typically nectar robbers and the nectar depletion by them may compel both pollinating bees and birds to make multiple visits to the flowers maximizing pollination rate. Further, the sunbirds also rob nectar from *Gardenia latifolia* Ait. which blooms at the same time in the same forest as a nectar source by making punctures at the base of corolla tube. The nectar robbing by sunbirds indicates that they do not have plant species that are appropriate for them during dry season at this forest site. Nevertheless, it is appropriate to state that *M. apetala* (Roth) M. Jacobs may have adjusted its flowering time to dry season to utilize birds available in the habitat as pollinators because honey bees are not effective pollinators *on par* with carpenter bees. The flowering time adjustment by *M. apetala* (Roth) M. Jacobs indicates the function of trade-off between flowering of this plant species in the unfavorable dry season and the better chance of pollination by certain birds at this time in addition to actual pollinators and hence, the situation of *M. apetala* (Roth) M. Jacobs in the deciduous forest is relatable to the situation of blooming of *M. crassifolia* Forssk. and other tree species during unfavorable dry season in the oasis of Ouadane in the western Sahara, Mauritiana, where migratory birds pollinate while they use the area as stopover site (Salewski et al., 2006). Further, *M. apetala* (Roth) M. Jacobs is an important bee plant during dry season at the forest site under study. Likewise *M. crassifolia* Forssk. has been reported to be a major pollen plant for bees in Oman (Sajwani et al., 2014, Abou-Shhaara, 2019). Therefore, *Maerua* species throughout their distribution range appear to be important as pollen plants for bees, especially for honey bees during dry season, whether they are efficient or not in effecting pollination.

Bird-flowers are usually red or orange (Rodriguez-Girones & Santamaria, 2004), produce no or only trace levels of volatile compounds (Knudsen et al., 2004), and offer a sufficient amount of dilute nectar as reward to pay for the high energetic costs of birds to visit them (Cronk & Ojeda, 2008). Plants adapted for pollination by birds are widespread and are typified by having large volumes of dilute nectar, reddish coloration and unscented flowers (Faegri & van der Pijl, 1979). A subset of these plant species restricted to the New World is adapted for pollination by hovering hummingbirds by having their flowers oriented toward open space (Westerkamp, 1990). Another subset of plant species is adapted for pollination by perching birds in the Old World (Fleming & Muchhala, 2008) and this version is largely supported by the amazing adaptations of plants pollinated by sunbirds which are the most specialized perching bird pollinators in the Old World. Plants pollinated by perching birds often produce a large number of flowers clustered into a dense inflorescence that enables nectar feeding from a single perching position (Ford & Johnson, 2008). But, the contention of evolution of hovering pollination only in the New World is recently challenged by the discovery of hovering pollination by Old World specialized passerine pollinators (Padysakova & Janecek, 2016). In Cameroon, the sunbird *Cyanomitra oritis* Reichenow hovers more frequently at the flowers of *Impatiens sakeriana* Hook.f. and collects nectar more quickly effecting pollination at a faster rate (Padysakova & Janecek, 2016). In South Africa, the sunbirds, *Nectarinia famosa* L. and *Cinnyris chalybeus* L. exhibit perching, hovering and hover-clasping to collect nectar from *Salvia africana-lutea* L.*, S. lanceolata* L.*, S. africana-caerulea* L. (Lamiaceae) and *Lycium afrum* L. (Solanaceae) (Wester, 2013). In the present study. *M. apetala* (Roth) M. Jacobs does not produce a large number of flowers clustered into dense inflorescences to enable nectar feeding by birds from a single perching position. The inflorescence is a corymbose raceme with 5-15 flowers oriented toward open space. The flowers lack corolla, emit fragrance from the stamens and produce a sufficient volume of nectar with moderate sugar concentration that is flexible for visitation by different classes of pollinators. Accordingly, bees and birds utilize the flowers as a nectar source. Among birds, sunbirds, *Nectarinia asiatica* Latham and *N. zeylanica* L. characteristically hover at the flowers to access the nectar situated in the calyx cup without contacting the stigma, and hence act as nectar robbers. Further, this hovering type probing enables them to collect nectar quickly than the other birds that employ perching type probing for nectar collection from *M. apetala* (Roth) M. Jacobs flowers. Therefore, this study further substantiates the findings of Wester (2013) and Padysakova & Janecek (2016) that sunbirds employ both perching as well as hovering mode to collect nectar from different plant species in the Old World. This is the first report from India.

The present study reports that *M. apetala* (Roth) M. Jacobs fruits with seeds embedded inside mature quickly during rainy season. They are indehiscent, disperse by gravity and hence are barochorous. The fallen fruits gradually decompose and expose seeds for germination. Fruits and seeds could not

be collected during the rainy season due to inaccessibility to the forest site. Field observations indicated that the forest floor is rocky and rough, and hence there is a remote possibility for the fruits and seeds to remain at the parental trees and to settle at favorable sites for their germination and seedling establishment. During the two-year study period, new emerging plants of *M. apetala* (Roth) M. Jacobs have not been found and hence, this plant appear to be struggling to build its population size in this forest. However, further studies on seed germination and recruitment aspects of *M. apetala* (Roth) M. Jacobs are required to understand the actors and factors contributing to its rare occurrence.

## Conclusions

In *Maerua apetala* (Roth) M. Jacobs is a temporally dioecous, obligately out-crossing species adapted for melittophily and ornithophily. Barochory is functional but recruitment at parental trees or elsewhere in the habitat is absent indicating that this tree species is on the verge of extirpation here. Therefore, it is recommended that foresters of the Idupulapaya Reserve Forest should take pertinent measures to restore the population size of the tree species by involving local people. Further, nesting sites of bee and bird pollinators need to be provided for their availability during the flowering season of the tree species for maximizing fruit/seed set.

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## References

Abou-Shaara H.F., 2019. Availability of nectar and pollen sources for honey bees in Oman. Journal of Agricultural Science 10, 13-19.

Ali S. 1979., The Book of Indian Birds. Bombay Natural History Society, Oxford University Press, Bombay.

Chayamarit K., 1991. Capparaceae. In: Flora of Thailand. Vol. 5. No. 3 K. Larsen and T. Smitinand (Eds.), pp. 266-268, Chutima Press, Bangkok.

Chhabra S.C., Uiso F.C., 1990. A survey of medicinal plants of Eastern Tanzania for alkaloids, flavonoids, saponins and tannins. Fitoterapia LXI, 307-316.

Cook J.A., Vanderjagt D.J., Pastuszyn A., Mounkaila G., 1998. Nutrient content of two indigenous plant foods of the Western Sahel: *Balanites aegyptiaca* and *Maerua crassifolia*. Journal of Food Composition and Analysis 11, 221-230.

Cronk Q., Ojeda I., 2008. Bird-pollinated flowers in an evolutionary and molecular context. Journal of Experimental Botany 59, 715-727.

Dafni A., Kevan P.G., Husband B.C., 2005. Practical Pollination Biology. Enviroquest Ltd., Cambridge.

De Wolf G.P., 1962. Notes on African Capparidaceae. III. Kew Bulletin 16, 75-83.

Faegri K., van der Pijl L., 1971. The principles of pollination ecology. Pergamon Press, Oxford.

Fleming T.H. (Ed.), Estrada A., (Ed.) 2012. Frugivory and seed dispersal: ecological and evolutionary aspects. Springer.

Ford C.M., Johnson S.D., 2008. Floral traits, pollinators and breeding systems in *Syncolostemon* (Lamiaceae). Plant Systematics & Evolution 275, 257-264.

Hiben M.G., Louisse J., de Haan L., 2019. Ethnomedicine and ethnobotany of *Maerua subcordata* (Gilg) DeWolf. Journal of Ethnic Foods 6, 23.

Hyde M.A., Wursten B.T., Ballings P., Coates P.M., 2020. Flora of Zimbabwe: Genus *Maerua.* https://www.zimbabweflora.co.zw/species data/genus.php.

Kers L.E., 2000. Capparidaceae (Capparaceae). In: Flora of Ethiopia and Eritrea, Vol. 2 (1), Magnoliaceae to Flacourtiaceae, S. Edwards, M. Tadese, S. Demissew and I Hedberg (Eds.), pp. 74-120, The National Herbarium, Addis Ababa University, Addis Ababa & Uppsala.

Khan M.L., Bhuyan P., Shankar U., Todaria N.P., 1999. Seed germination and seedling fitness in *Mesua ferrea* L. in relation to fruit size and seed number per fruit. Acta Oecologia 20, 599-606.

Knudsen J.T., Tollsten L., Groth I., Bergstrom G., Raguso R.A., 2004. Trends in floral scent chemistry in pollination syndromes: floral scent composition in hummingbird-pollinated taxa. Botanical Journal of Linnean Society 146, 191-199.

Miller A.G., Cope T.A., 1996. *Maerua crassifolia*. Flora of the Arabian Peninsula and Socotra. Vol. 1., Edinburgh University, UK.

Mishra A.K., Sharma M.P., Sing H., 2015. Floristic diversity of Delhi, India: a checklist. International Journal of Herbal Medicine 3, 8-18.

Nobsathian S., Bullangpoti V., Kumrungsee N., 2018. Larvicidal effect of compounds isolated from *Maerua siamensis* (Capparidaceae) against *Aedes aegypti* (Diptera: Culicidae) larvae. Chemical and Biological Technologies in Agriculture 5, 8.

Padysakova E., Janecek S., 2016. Sunbird hovering behavior is determined by both the forager and resource plant. Biotropica 48, 687-693.

Pullaiah T., 2000. Flora of Guntur District, Andhra Pradesh, India. Daya Books, New Delhi.

Pullaiah T., Muralidhara Rao D., 2002. Flora of Eastern Ghats: Hill Ranges of South East India. Vol. 1, Regency Publications, New Delhi.

Rodriguez-Girones M.A., Santamaria L., 2004. Why are so many bird flowers red? PLoS Biology 2, e350.

Sajwani A., Farooq S.A., Bryant V.M., 2014. Studies of bee foraging plants and analysis of pollen pellets from hives in Oman. Palynology 38, 207-223.

Salewski V., Almasi B., Schlageter A., 2006. Nectarivory of palearctic migrants at a stopover site in the Sahara. British Birds 99, 299-305.

Spittler G., 1983. Les Touaregs face aux secheresses et aux famines: Les Kelewey de lAir. Niger (1900-1985), Karthala, Paris.

Wester P., 2013. Sunbirds hover at flowers of *Salvia* and *Lycium*. Ostrich - Journal of African Ornithology 84, 27-32.

Westerkamp C., 1990. Bird-flowers - hovering versus perching exploitation. Botanica Acta 103, 366-371.