

Passerine bird-pollination in the Indian coral tree, *Erythrina variegata* var. *orientalis* (Fabaceae)

Erythrina variegata L. (= *E. indica* Lam.) var. *orientalis* (L.) Merr., a deciduous tree species is native to the coast of India and Malaysia, but widely introduced as an ornamental tree in the coastal areas of the Old World tropics¹. Except for a small note on the floral characteristics and flower-visitors by Ali², there is no information on the floral biology, breeding systems and pollinators of *E. variegata* var. *orientalis*. Therefore, these aspects have been studied during 2002 and 2003 for *E. variegata* var. *orientalis* found in Andhra University campus and at the hilly areas of Visakhapatnam, Andhra Pradesh, India. Twenty trees were used for making field observations and experimentation on the aspects described here.

Floral characteristics were examined for their relationship with the pollinators. Ten bagged flowers were used to measure nectar secretion rate and sugar concentration at 1 h intervals for two consecutive days. Sugar concentration was determined using a Hand Sugar Refractometer (Erma, Japan). The sugar types present in the nectar were recorded following the method by Harborne³. Stigma receptivity was tested by hydrogen peroxidase test⁴ at different times of the flower life. Hand-pollination tests were carried out for apomixis, autogamy (manipulated and unmanipulated), geitonogamy and xenogamy following the detailed procedure given in Solomon Raju and Subba Reddi⁵. One hundred and ten flowering inflorescences with 6496 flowers on ten trees were tagged and followed until pod set to determine the natural fruit-set rate. Bird visitors were observed during daytime from 0600 to 1800 h over a period of five weeks during each year of study. They were observed for their flower-probing behaviour and pollination role in *E. variegata* var. *orientalis*.

E. variegata var. *orientalis* is leafless during the flowering period. It flowers during February–March. The flowers are borne in dense, showy racemes at the tips of the branches. They mature and open in acropetal succession (Figure 1a). The flowers are large, odourless, bisexual and zygomorphic. The calyx is spathaceous and bilipped. The corolla is characteristically papilionaceous with one well-de-

veloped bright orange standard petal and two bright-red wing and two dark-red keel petals. Both wing and keel petals are poorly developed. The keel petals form a carinal-like structure and hold nectar inside. The stamens are ten, diadelphous and bear ditheous anthers. They form a staminal sheath basally and are free towards the apex. They bend upwards facing the standard petal. The ovary has a single carpel with 10–12 ovules. It is enclosed by the staminal sheath and the style comes out through the sheath and ends with a minute stigma.

The flowers open from 0530 to 0630 h. The standard petal unfolds the wing and keel petals exposing the stamens and stigma. The anthers dehisce by longitudinal slits about 1 h before anthesis. The stigma is receptive from anthesis onwards and remains so until the evening of the second day. Nectar secretion begins from anthesis onwards and continues for two consecutive days, if nectar is removed periodically. A flower produces $587 \pm 69.86 \mu\text{l}$ of nectar by 0800 h and if this nectar is not removed, the flower does not produce any additional amount of nectar in the remaining period of its life. When nectar is removed at fixed time intervals by micropipettes, the same flowers produced nectar continuously up to 1300 h on the first day and from 0630 to 1200 h on the second day. A flower produces $761.45 \mu\text{l}$ of nectar on the first day and $711.2 \mu\text{l}$ on the second day. The sugar concentration in nectar varied from 10.9 to 16.2% through the day in day-1 flowers and from 10.6 to 15.8% in day-2 flowers (Table 1). This variation in sugar concentration is attributable to evaporation of water in nectar due to a gradual increase in temperature and decrease in relative humidity through the day⁶. The sugars present in the nectar include sucrose, glucose and fructose; the last two are dominant.

E. variegata var. *orientalis* exhibits weak protandry and its role in precluding self-pollination is highly doubtful. The relative positions of the stamens and stigma indicate that there is a remote possibility for their natural contact with each other, so that pollination can occur within the flower. But, there is the possibility of pollen drop gravitationally on

the stigma lying below the anthers. Bagged flowers did not show pod set, but only those flowers that were hand-pollinated for autogamy showed pod set. This suggests that the flowers require vectors for pollen flow between anthers and stigma within and between flowers. The duration and pattern of nectar secretion and the timing and duration of stigma receptivity show that the flowers appear to have a preference for cross-pollination. The pod set percentage obtained through xenogamy conforms to this. In line with this, the natural pod set percentage is also low indicating that *E. variegata* var. *orientalis* is facultatively xenogamous and its function depends exclusively on pollinators (Table 2; Figure 1b).

In *E. variegata* var. *orientalis*, the inflorescences are small in number but long-lived for long-term attraction to flower-visitors. They are oriented horizontally and the flowers occur in the distal half, providing a standing place for flower-probing birds as reported by Baker *et al.*⁷ for palaeotropical *Erythrina* species which are pollinated by passerine birds. The flowers are bigger than insect-pollinated flowers, have red corolla and lack odour. The stamens and stigma are positioned in such a way that the probing birds contact them with their breast and head. Nectar is copiously produced and well protected in the keel petals. All these floral characteristics conform to ornithophilous pollination syndrome according to Faegri and van der Pijl⁸. The flowers are quite attractive to bird visitors in the leafless state during the flowering period. In the flower, the standard petal stands in an upright position and is the most conspicuous part of the flower; it is this which attracts bird-visitors by its colour. The red colour of the flower serves as an excellent signal of high calorific reward for bird-visitors⁹. Soon after flower-opening, the birds were found collecting nectar from the flowers of *E. variegata* var. *orientalis*. They foraged throughout the day, with more foraging activity during forenoon. The birds included both passerines and non-passerines. The passerines were *Dicrurus adsimilis* (black drongo; Figure 1c), *Acridotheres tristis* (Indian myna; Figure 1e), *A. fuscus* (jungle myna), *Sturnus*

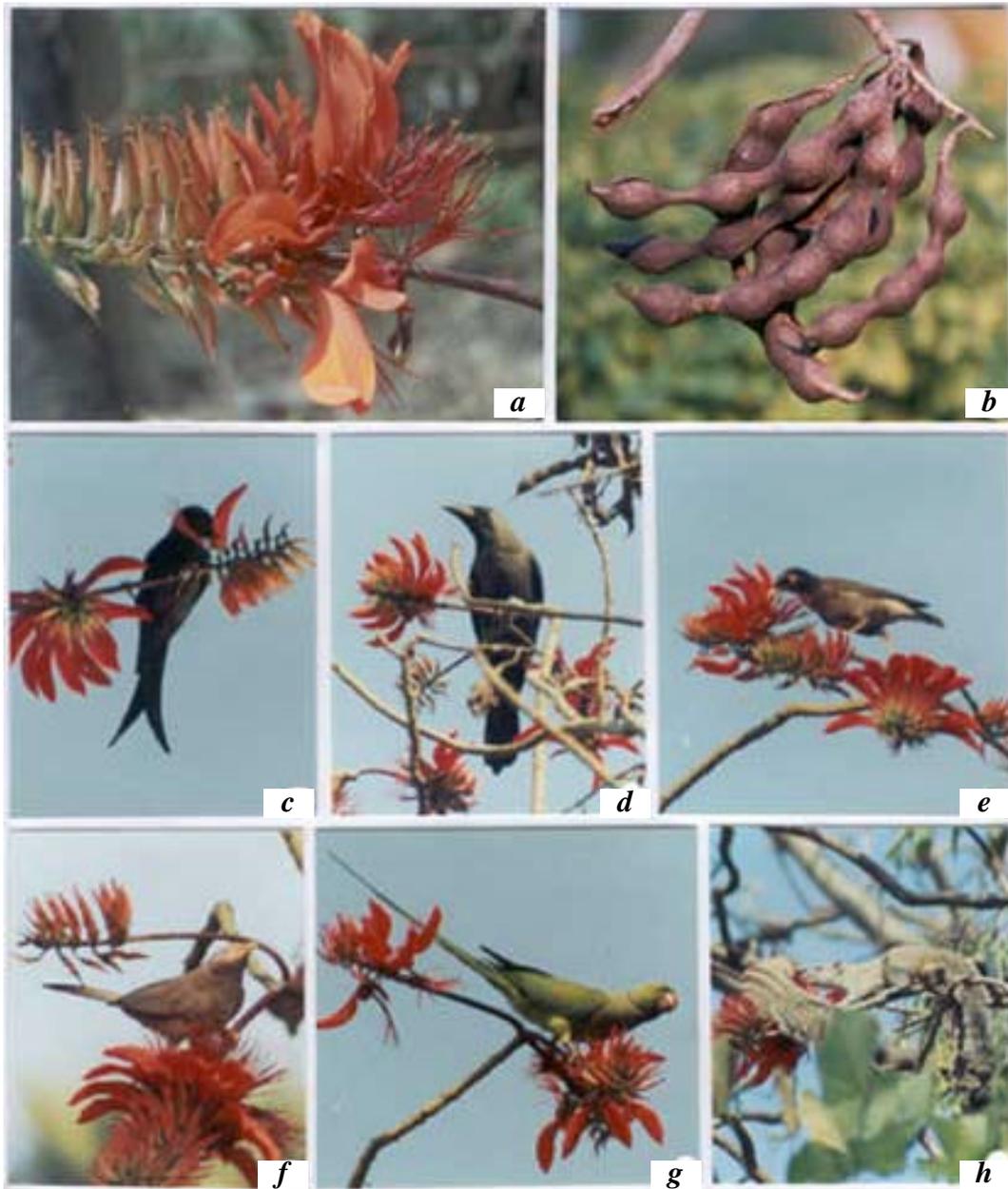


Figure 1. *Erythrina variegata* var. *orientalis*. **a**, Flowering raceme; **b**, Dry pods; **c–h**, Flower-visitors. **c**, Black drongo; **d**, House crow; **e**, Indian myna; **f**, Common babbler; **g**, Roseringed parakeet; **h**, Three-striped squirrel.

pagodarum (brahminy myna), *Corvus macrorhynchos* (jungle crow), *C. splendens* (house crow; Figure 1 *d*) and *Turdoides caudatus* (common babbler; Figure 1 *f*). The non-passerines were *Psittacula krameri* (roseringed parakeet; Figure 1 *g*) and *Dinopium benghalense* (goldenbacked woodpecker). Both categories of birds used the basal empty part of the inflorescence for landing. After landing, they gradually moved towards the flowers and probed them from the front for collecting nectar. While doing so, they contacted

the stamens and stigma with their beak, head and body, effecting pollination. Sometimes, they probed the flowers of nearby racemes and branches without hopping from the branches on which they have landed. The birds moved frequently between conspecific trees for more nectar to quench their thirst and this foraging behaviour is expected to promote cross-pollination. The non-passerines collected nectar also by damaging or removing the flowers. *D. adsimilis* mostly cut the staminal column and stigma to have access

to the deep-seated nectar, while *P. krameri* plucked flowers in quick succession in quest of nectar from as many inflorescences as possible. Therefore, nectar collection by non-passerine birds is mostly detrimental for the success of pollination in *E. variegata* var. *orientalis*. In addition to birds, a three-striped squirrel, *Funambulus tristriatus* (Figure 1 *h*) also ate flowers frequently, contributing to reduced fruit set in *E. variegata* var. *orientalis*.

Erythrina species pollinated by passerine birds in the tropical world produce

Table 1. Resumption of nectar secretion and sugar concentration following nectar removal in *Erythrina variegata* var. *orientalis*

Time (h)	Day-1 flower		Day-2 flower	
	Nectar volume/flower ($\bar{x} \pm SD$)	Sugar concentration (%) ($\bar{x} \pm SD$)	Nectar volume/flower ($\bar{x} \pm SD$)	Sugar concentration (%) ($\bar{x} \pm SD$)
0800	587 ± 69.86	10.9 ± 0.40	534 ± 75.65	10.6 ± 0.57
0900	123 ± 26.47	11.6 ± 0.44	117 ± 16.15	11.4 ± 0.65
1000	39 ± 4.35	12.1 ± 0.83	49.5 ± 14.56	11.6 ± 0.68
1100	6.5 ± 1.62	12.9 ± 0.92	6.5 ± 1.74	12.5 ± 0.72
1200	4.1 ± 1.13	14.0 ± 1.60	4.2 ± 1.09	13.3 ± 0.86
1300	1.85 ± 0.63	14.5 ± 1.50	No secretion	14.0 ± 0.96
1400	No secretion	14.7 ± 1.90		14.6 ± 1.05
1500		15.2 ± 2.10		15.0 ± 1.08
1600		15.4 ± 2.10		15.6 ± 1.18
1700		16.2 ± 2.30		15.8 ± 1.26

Table 2. Pod-set rate in different pollination modes in *Erythrina variegata* var. *orientalis*

Treatment	No. of flowers pollinated	No. of flowers set showing pod	Percentage of pod set
Apomixis	50	0	0
Autogamy (bagged)	50	0	0
Autogamy (hand-manipulated and bagged)	50	33	66
Geitonogamy	50	37	74
Xenogamy	50	48	96
Open-pollination	6496	293	4.5

hexose-dominated nectars. Sucrose, glucose and fructose, weight for weight, differ only slightly in calorific value, suggesting that energetics are not involved but that taste is involved¹⁰, because most of the passerine birds also feed at juicy or fleshy fruits. Fruit juices are almost always stronger in hexose sugars than in sucrose. Consequently, the passerine birds may have developed a taste search image which can be satisfied by hexose-dominated nectar¹⁰. In line with this, *E. variegata* var. *orientalis* also produces hexose-rich nectar and satisfies the taste and energy requirements of its passerine bird pollinators. Bolten and Feinsinger¹¹ reported that birds prefer concentrated sugar solutions, over dilute solutions but bird-pollinated flowers characteristically produce less concentrated nectar. Providing dilute nectar may be a mechanism that reduces visits by non-pollinating insects, thereby preventing reduction in the attractiveness of flowers to birds¹¹. In *E. variegata* var. *orientalis* also, the nectar sugar concentration is low but it produces copious amount of nectar and also nectar secretion is continuous for two days if nectar is removed continuously by birds, suggesting that

attractiveness of flowers overall is related not just to sugar concentration but to total energy content determined by volume and concentration¹². Further, in this species, the timing of nectar production in one- and two-day-old flowers nearly coincides with the timing of stigma receptivity and foraging activity of bird pollinators. These functional aspects of the flowers indicate that the relationship between *E. variegata* var. *orientalis* and passerine birds observed in this study appears to be mutualistic, the plant for achieving pollination and the birds for obtaining food. The non-passerine birds are not specialized flower-birds and their visits to the passerine, bird-visited flowers are only secondary, because they use floral nectar only under water stress conditions, especially during dry season. In India, passerine bird-pollination has been reported in *E. indica*, *E. stricta*, *E. cristagalli*, *E. suberosa* and *E. subumbrans*^{2,13}. These earlier studies and the present study suggest that *Erythrina* species in India and elsewhere in the Old World tropics^{1,8,14} have perfect bird-flowers adapted for pollination by passerine birds. These species flower during dry season and play a vital role in sustaining

bird species. They provide water, instant energy through sugars and also amino acids and proteins in their floral nectar. Further, these flowers also provide larvae and small insects to the visiting birds¹⁵. Therefore, *Erythrina* species provide both liquid and solid diet to the bird species, enabling the latter to survive during dry season.

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Biodiversity in the Western Ghats: The discovery of new species of caecilian amphibians

The suggestion¹ that the fauna of the Western Ghats (a recognized biodiversity hot spot²) includes many species of amphibians that await formal scientific description, has proven controversial³. The controversy largely revolves around whether these undescribed taxa are only now being recognized because of changes in taxonomic philosophy and methodology, or simply because of increased work that is uncovering biological reality. A recent article in this journal⁴ used a plot of cumulative species descriptions over time to support the latter explanation, by

showing that the species discovery curve has yet to reach an asymptote. It is noteworthy that the debate thus far, while cast in terms of amphibian diversity, has focused almost exclusively on frogs. We think it useful to broaden the empirical basis for the debate by considering also what is known of the taxonomy and biodiversity of the other order of amphibians that occur in the Western Ghats, the caecilians (Gymnophiona).

The species accumulation curve for the Western Ghats caecilians (Figure 1) indicates that the number of described spe-

cies is undergoing rapid expansion in this group, with no sign of reaching a plateau. That there remained many species of caecilians to be discovered and described from the Western Ghats was previously predicted⁵ on the basis of species encounter rates during survey work. Note that at the time that particular study was published (1997), the plot in Figure 1 had reached a plateau that can now be interpreted as a hiatus in discovery.

Why might so many Western Ghats amphibians still await discovery and description after more than 200 years of re-

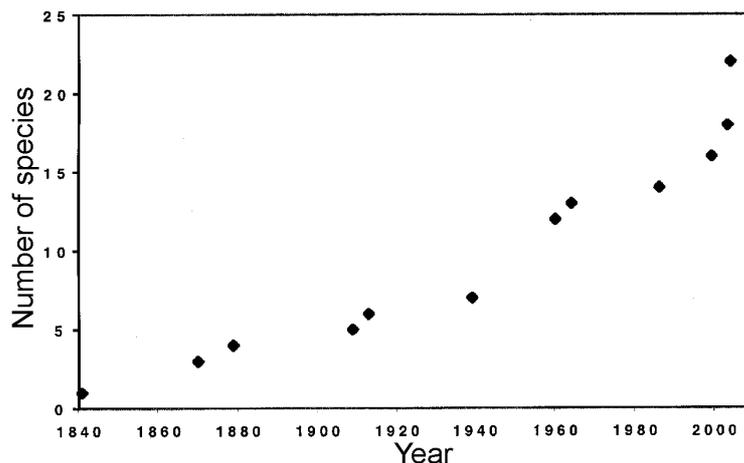


Figure 1. Historical pattern of description of caecilian amphibian species of the Western Ghats. We did not include *Ichthyophis glutinosus*⁹ or *I. sikkimensis* (the only caecilian species described from Northeast India that possibly occurs also in the Western Ghats⁹). Separate plots for Indian caecilians endemic and non-endemic to the Western Ghats were not produced because except for a couple of reports¹⁰ of records from the Eastern Ghats that require reassessment, all 22 species in the region are endemic. The datapoint for 2004 includes new species descriptions by the present authors that are in press or currently under review.