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FLORAL DIVERSITY, PHENOLOGY, AND POLLINATION MECHANISM OF TRUE VIVI-PAROUS AND CRYPTO-VIVIPAROUS MANGROVES OF GODAVARI AND KRISHNA DELTA OF ANDHRA PRADESH, INDIA

Jonathan Henry KARYAMSETTY *

Health, Safety and Environmental Management,
International College of Engineering and Management, Seeb, Muscat, Sultanate of Oman.

Abstract

Mangroves are salt tolerant plants that typically grow in inter-tidal zones and are referred to forests by the sea. Mangrove forests of Andhra Pradesh occur in Godavari and Krishna estuary inhabiting 35 mangrove species. The diversity of species in both the mangrove forests is different due to the change in geography of the location and disturbance from human intervention. Krishna mangrove forest has six true vivipary mangrove species with pure stands of Rhizophora species. 19 mangrove plants were studied to know the breeding mechanism, floral phenology, and reproductive phenomena of different groups of mangrove flora. Majority of plants commence flowering in summer and post monsoon periods and initiate fruiting subsequently. Cross and mixed breeding system is the most successful reproductive mechanism adopted by a good number of mangrove species studied revealed from the hand breeding experiments. The pollen carriers included bees, flies, butterflies, wasps, moths, birds, that acted as vectors and in-turn facilitated cross pollination in some species. The regeneration mode of mangrove plants is classified into three types, vivipary, crypto-vivipary and non-vivipary.

Keywords*: Vivipary; Crypto-vivipary; Pollen vector; Cross pollination; Breeding systems.*

Introduction

Mangroves are plant communities occurring in the inter-tidal zones along the coasts of tropical and subtropical countries [1-4]. They are one of the most productive ecosystems and are typically assemblage of flowering plants growing along the interface of marine and freshwater habitats [5]. They represent rich and diverse living resources and render livelihood and economy to fishermen communities and also help in protection of coastal environment.

Globally mangroves are distributed across the tropical and sub tropical forests and are predominantly found in the tropical region [6]. Asia and Australia have the greatest diversity and distribution of mangrove forests, more than 40 percent are found along the Asian coasts. While the largest mangrove formations are found in Indonesia [7], Brazil and Sundarbans of India [8-11] and Bangladesh [12-14].

The total mangrove forest in India represents 7 percent of the world's mangrove forest [11], whereas the total span of the world's mangrove forest covers 124 countries spreading

* Corresponding author: khjonathan@gmail.com

about 150,000 sq. km between 30˚N and 30˚S latitudes [15]. The extent of the mangrove forest in India including the permanently under water is about 6,740 sq. km [11]. The mangrove forests in India occur predominantly in East Coast, West Coast and the Bay Islands with East coast contributing 56 percent of the total mangrove cover in India. The East coast mangrove forests are distributed in West Bengal, Orissa, Andhra Pradesh, Tamil Nadu and Andaman and Nicobar Islands [5] and are rich in flora and fauna; while the west coast mangrove forests are present in the states of Maharashtra, Gujarat, Goa, and Karnataka [11].

The mangrove forests in Andhra Pradesh was 0.9 percent of the total forest area of the state in 2003 [6] and currently contribute 1.5 percent of the total forest area of the state [16]. The total area of the Godavari mangrove forest is 184 sq. km and moderately dense mangroves constitute 62 sq. km [16]. In this context, a brief report on some of the mangrove species are observed in the coringa mangroves of Andhra Pradesh and studied in detailed in conjunction with earlier studies reported on flowering phenology, reproductive biology, and conservation by various authors. A comparison of the regeneration mechanisms of few species is examined depending on their mode of seedling dispersal and subsequent establishment in the mangrove forest.

Materials and Methods

The mangrove forests in Andhra Pradesh are predominantly located in the estuaries of Godavari and Krishna River in Godavari and Krishna districts and sparsely distributed in Visakhapatnam, Srikakulam and Prakasam districts [17]. The Godavari mangroves are located in the Godavari estuary of east Godavari district and lay between 16º30'–17º00'N latitude and 82º10'- 80º23'E longitudes while the Krishna mangrove forests are situated between 15°40'N and 16°55'N latitude and 80°0' and 82°23'E longitudes [18]. The present study is taken in Godavari and Krishna mangrove forests of Andhra Pradesh that is shown in (Fig. 1).

Fig 1. Map showing the Godavari and Krishna delta mangrove forests of Andhra Pradesh.

Mangrove plants belong to several families, but possess marked resemblances in their physiological characteristics and structural adaptations. Godavari and Krishna mangroves have a record of 35 mangrove flora belonging to 27 genera of 20 families [6] while 24 species belonging to 19 genera and 15 families were reported according to [19]. Godavari mangrove forest is spread over nine reserve forests (R.F.) that have varying densities and distribution of mangrove flora. All the nine R.F. are surveyed for understanding the floral phenology and fruiting pattern of the mangrove flora. Observations were made for three successive years from 2005 till 2008 to record the flowering pattern and principal pollen vectors of the different mangrove flora in both the study areas. Frequent visits were made during the entire blooming period to record the insect vectors. The flower visitors are caught using nets and immobilized with ethyl alcohol, and later identified. Some of them are washed in ethanol for the presence of pollen on their body parts to ascertain their role in pollination or otherwise pollen carriers. For the present study 7 mangrove species were selected which include *Ceriops decandra* (Griff.) Ding Hou and *C. tagal* (Perr.) C.B. Rob. (Rhizophoraceae), *Aegialitis rotundifolia* Roxb. (Plumbaginaceae), *Aegiceras corniculatum* (L.) Blanco (Myrsinaceae), *Sonneratia apetala* Buch.-Ham. (Sonneratiaceae), *Derris trifoliata* Lour. (Fabaceae) and *Excoecaria agallocha* L. (Euphorbiaceae) from both the mangrove forests to understand and gather information on reproductive details such as breeding mechanism, flower visitors and their role as pollen vectors, analysis of flora rewards (pollen and nectar), floral phenology, seed set ratio and seedling dispersal mechanism. Biochemical aspects of flower nectar such as nectar sugar types, amino acids and protein estimation is carried as per [20]. Pollen protein estimation is quantified according to *O.H. Lowry et al.* [21], to know the quantification of total protein content in pollen per flower.

Results and Discussion

Of the selected plant species studied *C. tagal* and *A. rotundifolia* occur only in Krishna mangrove forest and hence were studied in this forest. The other five plant species occur in Krishna (Latitude 15°42'–15°55'N and Longitude 80°42'– 81°01'E) and Godavari (Latitude 16°30'–17°00'N and Longitude 82°10'-80°23'E) mangrove forests but the study was conducted on these species in Godavari mangroves only [15] (Fig. 1).

Of the 7-species examined, *Ceriops* species are true evergreen viviparous tree species, *A. rotundifolia* and *A. corniculatum* are evergreen shrubby crypto-viviparous tree species and the other three are non-viviparous species [22, 23] (Table 1). *S. apetala* is an evergreen tree species, *E. agallocha*, a semi-deciduous tree species while *D. trifoliata* is a deciduous woody climber. The last two species are distributed in oligo-haline to poly-haline zones. *A. corniculatum* is a meso-haline species, *C. decandra* and *S. apetala* poly-haline species while *C. tagal* and *A. rotundifolia* are eu-haline species.

Table 1. Mode of reproduction of selected mangrove species

Viviparous	Crypto-viviparous	Non-viviparous
Ceriops decandra	*Aegiceras corniculatum*	*Sonneratia apetala*
**C. Tagal*	**Aegialitis rotundifolia*	*Derris trifoliata*
		Excoecaria agallocha

* Species present in Krishna mangrove forest, not confirmed in Coringa forest.

All the species, except *E. agallocha* are hermaphroditic, self-compatible and exhibit mixed breeding system. *E. agallocha* is dioecious and obligately out-crossing. In all, the flowers offer nectar and pollen as rewards to flower visitors. The nectar volume, sugar concentration and sugar types were examined for all the species except *E. agallocha*; and nectar amino acids for five species except *D. trifoliata* and *E. agallocha*. Nectar is sucrose rich in *C. decandra*, *S. apetala* and *E. agallocha*; fructose rich in the following species *C. tagal*, *A. rotundifolia* and *A. corniculatum* while the *A. rotundifolia* is also rich in glucose (Table 2).

Table 2. Nectar Sugar types present in the studied mangrove plant species

Sugar type	*Ceriops decandra*	*Ceriops tagal*	*Aegialitis rotundifolia*	*Aegiceras corniculatum*	*Sonneratia apetala*	*Derris trifoliata*
Sucrose	+++	--	--	--	+++	+++
Fructose	++	+++	+++	+++	++	+
Glucose	++	++	+++	++	++	++

These nectar characteristics are suited for entomophily. Insects require ten essential amino acids and some of them are found in these plant species - arginine, histidine, phenylalanine, threonine, tryptophan, and valine in *C. decandra*; lysine and threonine in *C. tagal*; arginine, lysine, phenylalanine, threonine, tryptophan, valine, and histidine in *A. rotundifolia*; arginine, lysine, threonine, and histidine in *A. corniculatum*; and arginine, lysine, and histidine in *S. apetala* (Table 3).

Table 3. Nectar amino acids of the studied mangrove plant species

S. No.	Amino acid type	*Ceriops decandra*	*Ceriops tagal*	*Aegialitis rotundifolia*	*Aegiceras corniculatum*	*Sonneratia apetala*
1	Alanine	++	+++	+++	+++	++
2	Arginine*	+	--	++	+++	--
3	Aspartic acid	++	++	++	++	+++
4	Cysteine	+++	+++	++	+++	++
5	Cystine	++	+++	+++	+++	+++
6	Glutamic acid	+	+	++	+++	+++
7	Glycine	++	+++	+++	+++	+++
8	Histidine*	+	--	++	+++	+
9	Iso-leucine*	--	--	--	--	--
10	Leucine*	--	--	--	--	--
11	Lysine*	--	+	++	+++	++
12	Methionine*	--	--	--	--	--
13	Phenly-alanine*	+	--	+	--	--
14	Proline	--	--	+++	++	+++
15	Serine	++	+++	+++	+++	+++
16	Threonine*	+	++	+++	+++	--
17	Tryptophan*	+	--	++	--	--
18	Tyrosine	++	++	+	++	+++
19	Valine*	++	--	+++	--	--

+++: dominant, ++: moderate, +: traces, -- : absent. * essential amino acids for insects.

Further, pollen also contains protein, the amount of which varied with each plant species. The floral rewards are therefore important nutrient sources for different species of insect pollinators. Quantitative estimates of floral rewards of the mangrove plant species are given in (Table 4).

In *C. tagal*, the flowers are specialized and possess explosive pollination mechanism which is adapted for pollination by insects and also by wind while in *C. decandra*, the flowers are not specialized, have simple floral mechanism, and are adapted for pollination by bees and wasps, elsewhere they are also visited by trigonid bees and other small insects [24]. In *A. rotundifolia* and *A. corniculatum* also, the flowers are not specialized and promiscuous for foraging by any insects; the former species is characteristically melittophilous while the latter species is entomophilous, and in both the species, anemophily also occurs to some extent. The floral characteristics of *S. apetala* suggest chiropterophily but morning anthesis and the presentation of floral rewards during daytime facilitate foraging by day-active foragers only and accordingly, the plant is found to be primarily melittophilous and partly anemophilous. *D. trifoliata* flowers are specialized and exhibit explosive pollination mechanism which is adapted for tripping and subsequent pollination by insects. The short- and long-tongued bees trip the flowers and hence the plant is melittophilous. *E. agallocha* with male and female flowers on separate individuals is found to be both anemophilous and entomophilous. In sampled sites, the male trees are double the number of female trees, the ratio of male to female flowers is 16:1 and each male flower produces a copious amount of pollen. These characteristics are adaptations for anemophily. The long catkins of male trees and the short-mixed cymes of female trees with a number of flowers and the presence of several such inflorescences on each tree simultaneously are quite attractive to foragers. The yellow stamens and bright green shining styles appear to enhance attractiveness to foragers. The nectar is in traces in male flowers while it is relatively measurable in female flowers. These characteristics indicate that the plant is also evolved for pollination by insects. Insect-pollination is considered to be more economical than anemophily; in the latter mode of pollination, a huge amount of pollen is wasted, and it is also energetically expensive for the plant.

Table 4. Quantitative estimates of floral rewards of the mangrove plant species.

Plant species	Pollen protein content/flower (µg)	Nectar protein content/flower (µg)	Nectar sugar content/ flower (mg)	Pollen ovule ratio	Pollen size (µm)
C. decandra	24.0	--	0.66 ± 0.1	2135:1	16.6
C. tagal	21.6	48.11 ± 10.52	2.79 ± 0.5	2446:1	15
A. rotundifolia	30.04	--	3.60 ± 0.49	1443:1	119.52 ± 10.49
A. corniculatum	28.0	--	1.73 ± 0.39	2174:1	33.2
S. apetala	1.71 mg	13.94 ± 2.20	1.99 ± 0.51	420:1	41.5
D. trifoliata	6.0	--	0.43	1873:1	41.5
E. agallocha	9.0	--	--	35259.4:1	33.2

In all the studied species except *E. agallocha*, autogamy is a mode of pollination but fruit set rate in this mode is negligible in *Ceriops* species and *D. trifoliata*, and more in other species, but it is highest in *S. apetala*. In *E. agallocha,* anemophily assures the success of sexual reproduction in the absence of insect pollinators. Therefore, the ability to out-cross to

set fruit through anemophily in *E. agallocha* and the ability to self-pollinate and set fruit in the absence of insect pollinators in all the other plant species seems to be a "fail-safe" strategy for reproductive assurance during colonization or when conspecifics do not occur nearby. Mangrove areas are known for their harsh and uncertain environmental conditions and the ability of the studied plant species to reproduce sexually in the total absence of insect pollinators is highly adaptive for their survival and colonization.

Flower bud abortion occurs in *C. decandra, A. corniculatum, S. apetala* and *D. trifoliata*; it is highest in the first species. Natural fruit set rate is 16% in both species of *Ceriops*, 55-61% in *A. rotundifolia, A. corniculatum* and *S. apetala*, 29% in *D. trifoliata* and 92% in *E. agallocha*. In the last species, fruit predation is 25%; a beetle, *Chrysocoris patricius* consumed the fruits prior to their fall from the mother plant. Single-seeded fruit is the characteristic in *Ceriops* species in which each ovary contains 6 ovules and in *A. corniculatum* in which each ovary contains 35 ovules. *A. rotundifolia* flower is single-ovuled and produces a single seed. In *S. apetala*, each fruit produces an average number of 118 seeds against an average number of 488 ovules per ovary and fruit abortion takes place to an extent of 11%. In *D. trifoliata*, 1-3 seeds are produced per pod although the ovary contains 6 ovules. The recorded natural fruit set rates, ovule abortion, fruit abortion and reduced seed set rate were considered to be related to the pollination rate, elimination of genetically inferior seeds prior to their maturation and to the availability of nutrient resources to the parent plant.

In all the studied species, seeds are not dormant. In *Ceriops* species, the seed produces naked seedling while it is still attached to the parent plant; the seedling is small and erect in *C. decandra* but it is longer and in hanging position in *C. tagal*. In both the species, a yellow collar is visible separating fruit from the seedling. In *A. rotundifolia* and *A. corniculatum* also, the seed produces seedling within the fruit pericarp while it is still attached to the parent plant; the seedling is erect in the former and hang downwards in the latter species. The seedling of *A. rotundifolia* is relatively larger than that of *A. corniculatum*. These are important field characteristics to identify the plants during their fruiting season. The fruits hang downwards in *S. apetala*, are horizontal or vertical in *D. trifoliata*, and erect in *E. agallocha*. In these non-viviparous species, seed is the propagule and it does not germinate on the parent plant but germinates when settled in the parental or other sites. In all the species except *C. tagal*, seedling or seed dispersal and establishment occurs through self-planting and stranding strategies. In *C. tagal*, seedling dispersal and establishment occurs through self-planting strategy only. The self-planting strategy is effective in undisturbed sites while the stranding strategy is more effective in exploited and open areas of mangroves.

Conclusion

The study suggests that the characteristics such as sexual system, mixed breeding system, self-pollination with or without wind or insects, vivipary, crypto-vivipary and non-vivipary, self-planting and stranding strategies are adaptations in the studied plant species for survival and colonization in mangrove areas. The plants are important nectar and pollen sources for different insect species for their own survival and for raising their offspring. The relationships between mangrove plants and insects are mutualistic, the former for reproductive success and the latter for food. Therefore, these relationships are important and are vital for structuring and sustaining mangrove forests locally and elsewhere worldwide.

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