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Pollination ecology of *Litsea deccanensis* Gamble (Lauraceae), a commercially and medicinally important semi-evergreen tree species

Kunuku Venkata Ramana[1], Balaramaswamy Yadav P[1], Aluri Jacob Solomon Raju[2]✉

1.Department of Botany, Andhra University, Visakhapatnam 530 003, India
2.Department of Environmental Sciences, Andhra University, Visakhapatnam 530 003, India

✉**Corresponding author:**
A.J. Solomon Raju, Mobile: 91-9866256682, E-mail: solomonraju@gmail.com

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ABSTRACT

Litsea deccanensis is a semi-evergreen wet season blooming tree species. It displays dioecy with staminate and pistillate trees occurring in 2.8:1 ratio at the study location. The inflorescence is a solitary and compound pseudo-umbel with involucral bracts each one producing several staminate or pistillate nectariferous florets. The floral traits indicate myophily but in reality the tree species is entomophilous. Natural fruit set rate stands at the most 16%. Barochory and zoochory are the modes of fruit dispersal.

Key words: *Litsea deccanensis,* dioecy, entomophily, barochory and seed dispersal by squirrels.

1. INTRODUCTION

Litsea with more than 300 species in the family Lauraceae is distributed mostly in tropical Asia although it extended its distribution in the Islands of the Pacific, Australia and in the North and Central America (Van der Werff, 2001). Revisions of regional flora in tropical Asia indicated the distribution of 74 species in China (Huang et al. 2008), 35 in Thailand (Ngernsaengsaruay et al. 2011), 11 in Nepal (Pendry, 2011) and 45 in India of which *L. assamica, L. beddomei, L. bourdillonii, L. coriacea, L. floribunda, L. ghatica, L. keralana, L. laevigata, L. membranifolia, L. mishmiensis, L. mysorensis, L. nigrescens, L. oleoides, L. oreophila, L. stocksii, L. travancorica, L. venulosa* and *L. wightiana* are endemics (Bhuinya et al. 2010).

In Lauraceae family, very little information is available on the pollination aspects of any species despite their high commercial value. Nalini and Nathaniel (2000) noted that Lauraceae members are pollinated by generalist insects such as Hymenoptera, Diptera and Lepidoptera. Soubadra Devy and Davidar (2006) mentioned that *Litsea* sp. is dioecious and pollinated by social bees in the southern Western Ghats of India. Ci et al. (2008) noted that *L. szemaois* is entomophilous. Corlett (2001) reported that *L. glutinosa* is predominantly foraged by *Apis cerana* but with most visits to male flowers. House (1985, 1989, 1992, 1993) reported that *L. leefeana* has unspecialized entomophilous pollination syndrome but it is predominantly myophilous.

Litsea deccanensis is an endemic evergreen tree species distributed in the deciduous forests of South India (Irulandi et al. 2016). It serves as a larval host tree species for the Papilionid butterfly, *Papilio clytia* (Kunte, 2000). This tree species is a source of aklaloids, phenolic acid and flavonoids. The leaves are valued in folk medicine for chest pain by tribal people in Andhra Pradesh, India (Kumar et al. 2011). Its bark has commercial value due to which it is over-harvested unscientifically as a consequence of which its population is on gradual decline (Mishra and Ramakrishna Naidu, 2013). Our field surveys in Seshachalam Biosphere Reserve in Chittoor District of Andhra Pradesh, India, indicated that *L. deccanensis* with 20 individuals is restricted to downhill and foot hill of the Reserve. Since this tree species is in endangered state, the present study was made to describe its pollination ecology to understand sexual reproduction aspects and take measures for its conservation and management in *in situ* or *ex-situ* and also for its cultivation in deciduous eco-regions to provide livelihood opportunities for the locals who clear cut the wild trees of this species.

2. MATERIALS AND METHODS

Twenty individuals of *Litsea deccanensis* occurring in the Seshachalam Biosphere Reserve in Chittoor District of Andhra Pradesh in South India (13°42.539 N latitude and 079°20.566 E longitude, and 2,541 ft altitude) were used for the study during January-December 2017. Local people in this area over-harvested its bark until a few years ago but now the Government of India banned the collection of any biological resources by declaring the entire area as a Biosphere Reserve. Field trips were conducted at weekly intervals to record the timing different phenological events. During flowering season, twenty inflorescences collected randomly from fifteen trees were examined in the field and in the laboratory to identify the floral sexual status. After identifying sexual differences in the flowers, the trees were designated as staminate and pistillate and also accordingly their sex-ratio was enumerated. Flowering phenology was documented using 12 staminate and 5 pistillate trees; each tree was tagged and followed to record first and last flowers in order to define flowering duration of each individual. Based on chosen numbers as given in Tables 1-3, the production rate of involucral buds/umbels, florets produced per involucral bud/umbel and stamens/staminodes produces per floret was recorded in both staminate and pistillate trees. Solitary and compound involucral umbels were collected from staminate trees to calculate the pollen output separately in solitary involucral bud and umbels with 2, 3 and 4 involucral buds; the data along with the sample size for each umbel type were presented in Table 4. Production rate of nectar glands in florets in staminate and pistillate trees was also recorded and the data were presented in Table 5. Ten involucral umbels each on staminate and pistillate trees were tagged and followed to record anthesis schedule and anther dehiscence. Twenty five fresh involucral buds each consisting of several florets were collected from staminate and pistillate trees to record the floral morphological details of staminate and pistillate florets. The pollen output and stigma receptivity aspects were examined using the protocols described in Dafni et al. (2005). The umbels of both sexes were examined during their anthesis for the presence and the foraging activity of thrips.

Insects foraging on the involucral umbels of both staminate and pistillate trees were observed day-long on four consecutive days to record their foraging behavior and role in pollination. The foraging visits of insects were recorded for fifteen minutes at each hour during the day to record the percentage of their foraging visits. Further, the same data were used to figure out the percentage of foraging visits made by each insect category. Ten specimens of each insect species were captured from staminate trees during peak foraging period, brought to the laboratory, washed in ethyl alcohol, stained with aniline-blue on a glass slide and observed under microscope to count the total pollen grains present and then calculate the mean number of pollen grains to know the pollen carrying efficiency.

Fruit and seed set rates in pistillate trees was recorded separately in involucral umbels with varying number of florets ranging from 8-16; a total of 318 involucral umbels was used for this aspect. Further, a total of 256 florets tagged on six pistillate trees and exposed to insect activity were followed for one month to record natural fruit/seed set rate. As the pistillate florets produce a single ovule per ovary, seed set rate was treated as equivalent to fruit set rate. Fruit maturation period, seed dispersal and seedling ecology aspects were briefly observed from the fruit initiation to seed dispersal time at 2-day intervals in the field.

Figure 1 *Litsea deccanensis* - Staminate trees: a. Habitat, b. Individual trees, c. Trunk. @Prof. Jacob Solomon Raju Aluri.

3. RESULTS

Phenology

It is a medium-sized semi-evergreen species with staminate and pistillate trees. The stem forms well developed trunk in mature and aged trees with 10 to 15 mm thick brown bark. All plants parts are soft and pale velvety except the upper leaf surface. Leaves are spirally arranged, papery, elliptic to oblong to obovate. Leaf tip is blunt, pointed or tapering and base is rounded. The staminate and pistillate trees occur in the ratio of 2.8:1 in the study area (Figure 1 & 3). In staminate trees, 2% of sampled flowers were found to be morphologically and functionally bisexual. In both sexes, leaf fall begins in early April and ends in late May while leaf flushing begins in late April and ends in June. Flower bud initiation occurs in July while flowering begins in September and ends in November with peak flowering in October (Figure 2a-d). Individual staminate and pistillate trees flower for about 3 weeks only. Flat-topped grey pubescent pseudo-umbel inflorescences are borne in leaf axils and each umbel consists of 1-4 pedicellate involucral buds in both staminate and pistillate trees. Solitary involucral buds are also borne in considerable numbers along branchlets, axils of leaves and at apex of branchlets. In staminate trees, the percentage of solitary involucral buds is 64% and that of pseudo-umbels is 36%. The percentage of pseudo-umbels with 2-involucral buds is 23%, 3-involucral buds 10% and 4-involucral buds 3%. In pistillate trees, the percentage of solitary involucral buds is 70% and of pseudo-umbels is 30%. The percentage of pseudo-umbels with 2-involucral buds is 24% and 3-involucral buds 6% (Table 1). Each involucral bud has 25 ± 0.4 mm long (Range = 19-33 mm) stalk in staminate trees and 18 ± 1.6 mm long (Range = 17-22 mm) stalk in pistillate trees. It has four pale green decussate sepaloid and tomentose bracts. Inner bracts are papery while outer bracts are leathery; both are covered with soft and velvety hairs in both sexes. In both sexes of trees, the involucral buds have identical inner and outer bracts with almost the same length and width. The inner bracts are 11 ± 0.7 mm long (Range = 10-12 mm) and 10 ± 0.8 mm wide (Range = 9-11 mm) while the outer bracts are 10 ± 0.9 mm long (Range = 9-12 mm) and 10 ± 0.8 mm wide (Range 9-11 mm). In staminate trees, an involucral bud encloses 12.3 ± 1.8 (Range 9-16) florets; the percentage of 9-floreted involucral buds is 5%, 10-floreted buds 8%,11-floreted buds 17%, 12-floreted buds 15%, 13-floreted buds 20%, 14-floreted buds 22%, 15-floreted buds 10% and 16-floreted buds 3%. In pistillate trees, an involucral bud encloses 12.1 ± 1.8 (Range 8-16) florets; the percentage of 8-floreted involucral buds is 3%, 9-floreted involucral buds 7%, 10-floreted involucral buds 11%, 11-floreted involucral buds 14%, 12-floreted involucral buds 18%, 13-floreted involucral buds 23%, 14-floreted involucral buds 15%, 15-floreted involucral buds 8% and 16-floreted buds 1% (Table 2). In both staminate and pistillate

trees, the solitary involucral buds and pseudo-umbels with involucral buds act as unified flowers, with all their florets opening together synchronously in a time span of 5-6 hours during 0600-1200/1300 h daily (Figure 4a-j).

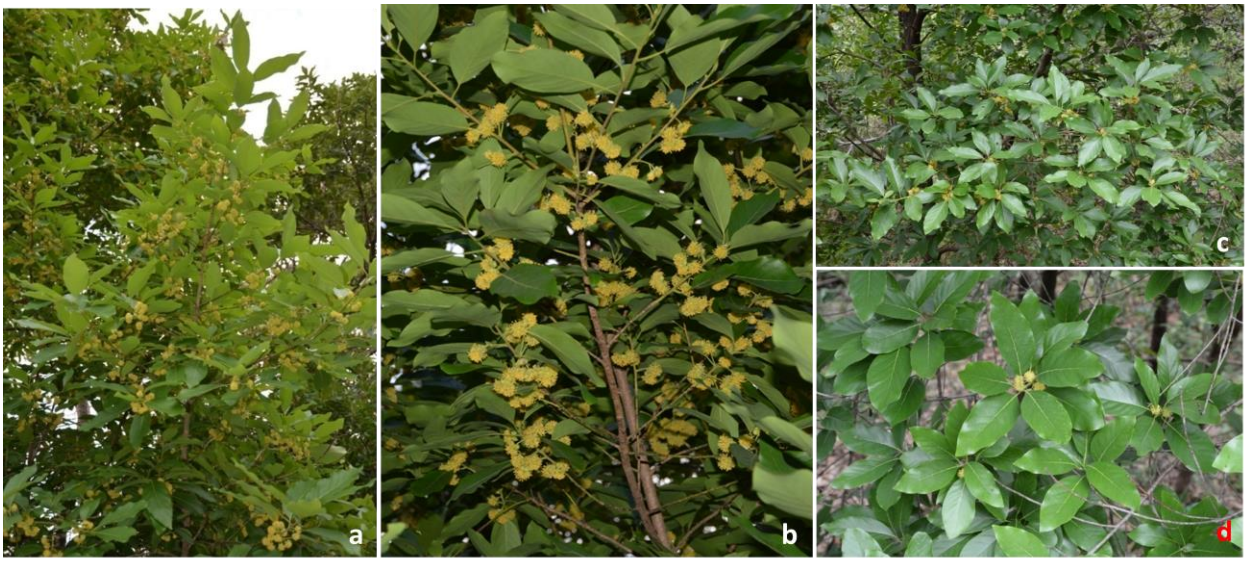

Figure 2 *Litsea deccanensis* - Staminate trees: a. Flowering branches, b-d. Axillary inflorescences flowering. @Prof. Jacob Solomon Raju Aluri.

Figure 3 *Litsea deccanensis* - Pistillate trees: a. Habitat, b. Individual trees, c. & d. Trunk. @Prof. Jacob Solomon Raju Aluri.

Table 1 Production rate of involucral buds or umbels in staminate and pistillate trees of *Litsea deccanensis*

Production rate of involucral bud/umbel	Staminate trees				Pistillate trees			
Number of involucral buds/umbels produced	1	2	3	4	1	2	3	4
No. of involucral buds/umbels recorded	182	65	28	10	213	73	19	0
Percentage (%)	64	23	10	3	70	24	6	0

N = 285, Range = 1-4, Average =1.5, S.D=0.8; N = 305, Range=1-3, Average =1.3, S.D=0.5

Table 2 Production rate of florets per involucral bud or umbel in staminate and pistillate trees of *Litsea deccanensis*

Production rate of florets/involucral bud/umbel	Staminate trees								Pistillate trees							
No. of florets produced/ involucral bud	9	10	**11**	**12**	**13**	**14**	15	16	8	9	10	**11**	**12**	**13**	**14**	15	16
No. of. florets recorded/ involucral bud	14	20	**42**	**37**	**49**	**56**	24	8	6	15	21	**28**	**36**	**45**	**30**	16	3
Percentage (%)	5	8	**17**	**15**	**20**	**22**	10	3	3	7	11	**14**	**18**	**23**	**15**	8	1
N = 250, Range = 9-16, Average =12.3, S.D = 1.8									N = 200, Range = 8-16, Average =12.1, S.D = 1.8								

Table 3 Production rate of stamens and staminodes/floret in staminate and pistillate trees of *Litsea deccanensis*

Production rate of stamens/staminodes/ floret	Staminate trees											Pistillate trees											
No. of stamens/staminodes produced/floret	10	11	12	13	14	**15**	**16**	**17**	18	19	20	21	13	14	15	16	17	**18**	**19**	**20**	21	22	23
No. of stamens/staminodes recorded/floret	1	1	4	8	11	**27**	**31**	**22**	16	11	4	1	4	8	13	18	24	**37**	**31**	**26**	22	15	2
Percentage	1	1	3	6	8	**20**	**22**	**16**	11	8	3	1	2	4	6	9	12	**19**	**16**	**13**	11	7	1
N = 137, Average = 16.05, S.D = 1.9, Range = 10- 21												N= 200, Mean = 18.3, S.D =2.2, Range = 13-23											

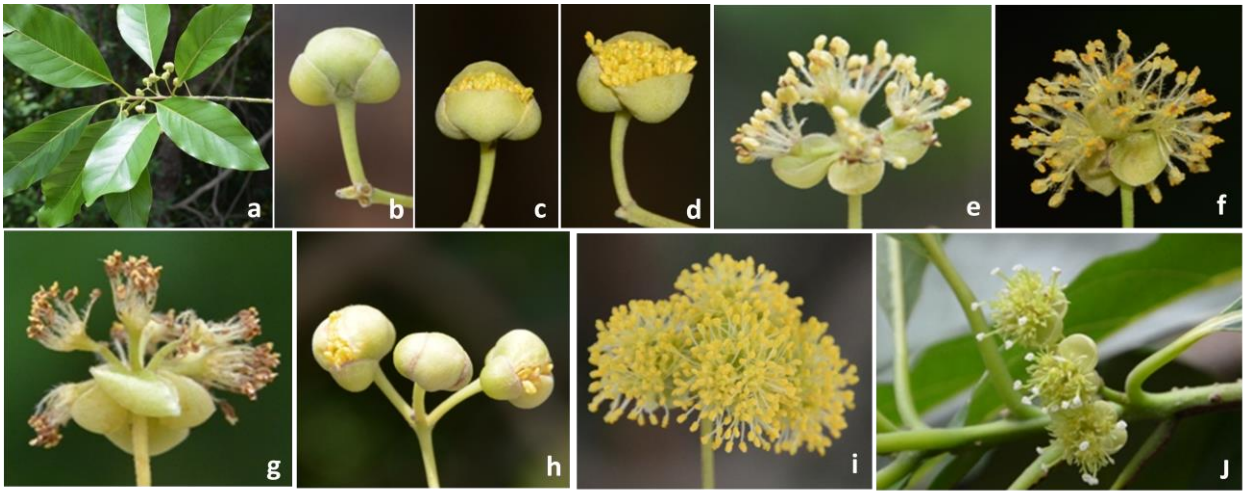

Figure 4 *Litsea deccanensis*: a. Twig with staminate umbels, b-g. Different stages of anthesis and anther dehiscence of staminate florets of a single umbel, h. & i. Anthesis and anther dehiscence of staminate compound umbel, j. Anthesis of pistillate umbels. @Prof. Jacob Solomon Raju Aluri.

Table 4 Pollen output in pseudo-umbels of staminate florets in *Litsea deccanensis*

Pseudo-umbel type	Floret number (Mean)	Total number of stamens	Pollen output
Solitary involucral bud	12	192	1,54,483.6
Pseudo-umbel with 2-involucral floret	24	384	3,08,966.4
Pseudo-umbel with 3-involucral floret	36	576	4,63,449.6
Pseudo-umbel with 4-involucral floret	48	768	6,17,932.8

Table 5 Production rate of nectar glands/floret in staminate and pistillate trees of *Litsea deccanensis*

Production rate of nectar glands produced/floret	Staminate trees													Pistillate trees									
No. of glands produced/floret	5	6	7	**8**	**9**	**10**	**11**	12	13	14	15	7	8	9	10	**11**	**12**	**13**	14	15	16	17	18
No. of. florets with glands produced	4	2	14	**27**	**19**	**22**	**23**	15	8	1	2	1	4	5	12	**19**	**25**	**32**	13	10	8	4	2
Percentage (%)	3	1	10	**20**	**14**	**16**	**17**	11	6	1	1	1	3	4	9	**14**	**18**	**24**	10	7	6	3	1
	N= 137, Range = 5 – 15, Mean = 9.6, S.D = 2.0													N = 135, Range = 7-18, Mean = 12.5, S.D = 2.1									

Staminate flower morphology and biology

The florets are borne on 2-3 mm long pedicels. They are pale yellow, slightly foetid, 7.1 ± 0.7 mm long, 11 ± 0.3 mm wide and actinomorphic. Perianth is not a characteristic feature. In an involucral bud, usually the peripheral flowers have perianth lobes while the inner flowers lack perianth lobes. In flowers with perianth lobes, they are commonly 1-lobed and rarely 2-lobed. They are creamy white, 2-5 mm long and strongly villose. The stamens vary in number ranging from 10-21 (16 ± 1.9) and arranged in 2-3 whorls without any fixed number in each whorl. The percentage of 10-stamened florets is 1%, 11-stamened 1%, 12-stamened 3%, 13-stamened 6%, 14-stamens 8%, 15-stamened 20%, 16-stamened 22%, 17-stamened 16%, 18-stamened 11%, 19-stamened 8%, 20-stamened 3% and 21-stamened 1% (Table 3). The stamens in outer whorl are the longest while those in the innermost whorl are the shortest and accordingly the length of the filament decreases from the outermost whorl of stamens to the innermost whorl of stamens. The filaments are creamy white, villose and have short-stalked fleshy glands as swollen pads of tissue at base; some filaments have two glands, one on each side, some others have one gland on one side and still some others none. The total glands in a floret vary from 5 to 15 (Table 5). The anthers are yellow, fertile, introrse, semi-orbicular and 4-celled. The pistillode is green, glabrous and has well developed ovary but ovule is absent; the ovary is tipped with residual remains of style and stigma. The anthers dehisce gradually during 0800-1200 h on the next day in all the florets of both solitary and compound umbels. They show valvular mode of dehiscence in which each anther locule wall opens through a flap of tissue. In effect, the pollen is exposed and placed on the upper surface of flaps but a small amount of pollen remains in the anther locule. The pollen output is 804.6 ± 78.3 (Range 710-923) per anther and 12,873.6 ± 1,253.3 per flower (Range = 11,360-14,768); it is 1,54,483.6 in 1-involucral umbel, 3,08,966.4 in 2-involucral umbel, 4,63,449.6 in 3-involucral umbel and 6,17,932.8 in 4-involucral umbel (Table 4). The pollen grains are slightly wet during anther dehiscence and become dry and powdery gradually. They are spherical, 48.1 ± 6.9 µm (Range 41.5-58.1 µm), apolar and spinulose. The glands attached to the base of the staminal filaments secrete nectar only once immediately after anthesis; their cuticle breaks down and the epidermis disintegrates around the glandular surface shortly before anthesis. The secreted nectar passes through the intercellular spaces of the basal tissue and the breakdown of the epidermal cells contributes to the ejection of the sticky secretion to the glandular surface. This nectar appears as droplets and glistens against sunlight. The villose base encloses the glandular portion of the filaments to contain and protect the nectar droplets. The involucral bracts together with florets fall off on 4th day.

Pistillate flower morphology and biology

The florets are borne on 2-3 mm long pedicels. They are pale yellow, slightly foetid, 6.1 ± 0.7 mm long, 5.6 ± 0.6 mm wide and actinomorphic. In an involucral bud, usually the peripheral flowers have perianth lobes while the inner flowers lack perianth lobes. In flowers with perianth lobes, they are commonly 1-lobed and rarely 2-lobed. They are creamy white, 2-3 mm long and strongly villose. The staminodes are villose, creamy white and vary in number ranging from 13 to 23 (18.3 ± 2.2) and arranged in three whorls without any fixed number in each whorl. The percentage of 13-staminoded florets is 2%, 14-staminoded 4%, 15-staminoded 6%, 16-staminoded 9%, 17-staminoded 12%, 18-staminoded 19%, 19-staminoded 16%, 20-staminoded 13%, 21-staminoded 11%, 22-staminoded 7% and 23-staminoded 1% (Table 3). The staminodes in the outer whorl are the longest while those in the innermost whorl are the shortest. Small stalked fleshy glands as swollen pads of tissue are attached to the base of the staminodes; some staminodes have two glands, one on each side, some others have one gland on one side and still some others none. The total glands in a floret vary from 7 to 18 (Table 5). The pistil is green, glabrous, 5. 7 ± 0.6 mm long (Range = 5-7 mm) and consists of well developed ovary, style and stigma. The ovary is ovoid, unilocular with a single ovule. The style is 3.6 ± 0.4 mm long (3-4 mm), filiform and topped with a peltate slightly bi-fid papillate, wet and shiny stigma. The stigma extends beyond the height of staminodes.

The stigma becomes receptive after the anthesis of involucral bud and ceases receptivity around noon of the 3rd day. The glands attached to the base of the staminodes secrete nectar only once immediately after anthesis; their cuticle breaks down and the epidermis disintegrates around the glandular surface shortly before anthesis. The secreted nectar passes through the intercellular spaces of the basal tissue and the breakdown of the epidermal cells facilitates the ejection of the sticky secretion to the glandular surface. This nectar appears as droplets and glistens against sunlight. The villose base encloses the glandular portion of the staminodes to contain and protect the nectar droplets. The involucral bracts and un-pollinated florets fall off on the 4th day.

Thrips breeding and feeding in staminate and pistillate involucral buds/umbels

Thrips used the involucral buds of both staminate and pistillate trees for breeding and emerged out during anthesis. Each bud contained several thrips ranging from 8 to 10. They foraged for nectar on the day of anthesis and for nectar and pollen after anther dehiscence on the next day. Their foraging activity was restricted to the same tree from whose flowers they emerged and hence the thrips were treated as forage robbers due. However, their foraging activity was found to be promoting the foraging activity of the pollinators on staminate and pistillate trees, and between both sexes.

Insect foraging activity and pollination

The umbels of both staminate and pistillate trees were foraged during day time by the same species of bees, wasps, flies and butterflies (Table 6). Bees were *Apis cerana* (Figure 5a,b), *A. florea* and *Trigona iridipennis* (Figure 5c). The wasp was *Vespa bicincta* (Figure 5d). The flies were *Chrysomya megacephala* (Figure 5g), *Sarcophaga* sp. and *Eristalinus arvorum* (Figure 5e,f). The butterflies included one lycaenid *Rapala iarbus* (Figure 5h) and one hesperiid *Hasora chromus* (Figure 5i). Of these, bees and the fly, *E. arvorum* foraged for both pollen and nectar while all others foraged for nectar only. Of these insects, *Apis* spp. and *E. arvorum* were regular and consistent foragers while all others were regular but not consistent foragers during the entire period of flowering. The foraging activity of these insects began at 0800 h, gradually reached to a peak at noon and then gradually decreased towards evening; they ceased foraging activity by 1800 h (Figure 6). Bees made 38%, flies 35%, butterflies 14% and wasps 13% of the total foraging visits in a day (Figure 7). The body washings of these insects collected from the florets around noon time showed that all of them were pollen carriers to different rates but pollen recovered from the bees was the highest (Table 7).

Table 6 List of insect foragers on *Litsea deccanensis*

Order	Family	Genus	Species	Common name	Forage sought
Hymenoptera	Apidae	*Apis*	*cerana* F.	Indian Honey Bee	Pollen +Nectar
		Apis	*florea* F.	Dwarf Honey Bee	Pollen + Nectar
		Trigona	*iridipennis* Smith	Stingless Bee	Pollen + Nectar
	Vespidae	*Vespa*	*bicincta* L.	Yellow Banded Wasp	Nectar
Diptera	Calliphoridae	*Chrysomya*	*megacephala* F.	Oriental Latrine Fly	Nectar
	Sarchophagidae	*Sarcophaga*	sp.	Flesh Fly	Nectar
	Syrphidae	*Eristalinus*	*arvorum* F.	Hover Fly	Pollen +Nectar

Lepidoptera	Lycaenidae	*Rapala*	*iarbus* F.	Indian Red Flash	Nectar
	Hesperidae	*Hasora*	*chromus* Cramer	Common Banded Awl	Nectar

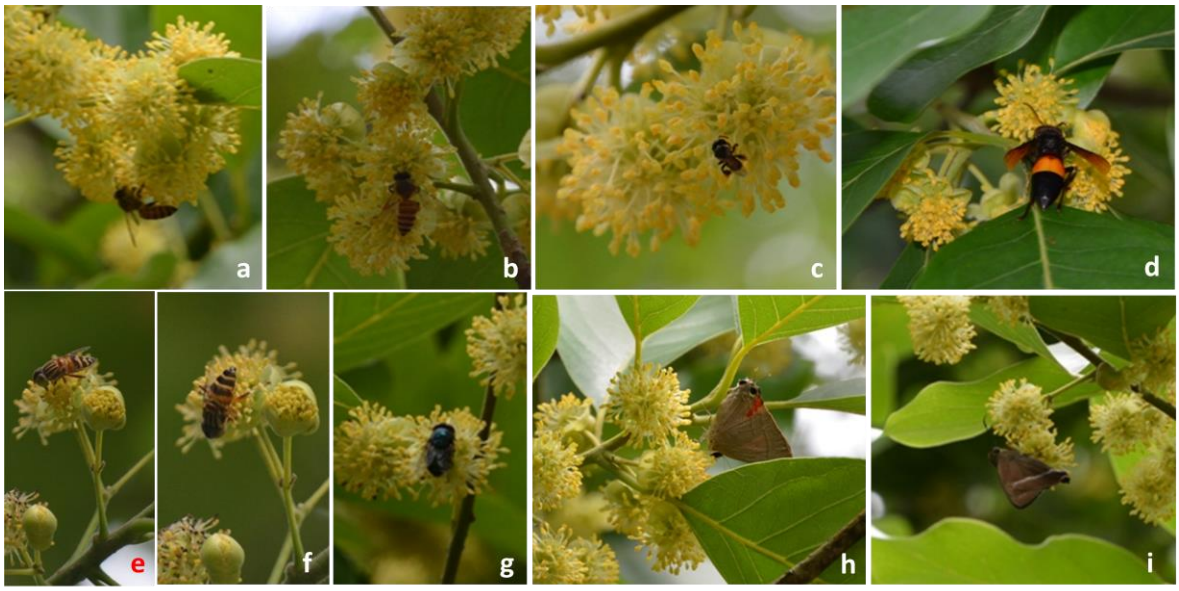

Figure 5 *Litsea deccanensis* - Insect foragers: a. *Apis cerana* collecting pollen, b. *Apis cerana* collecting nectar, c. *Trigona iridipennis* collecting pollen, d. *Vespa bicincta* collecting nectar, e. & f. *Eristalinus arvorum* collecting nectar, g. *Chrysomya megacephala* collecting nectar, h. Lycaenid butterfly, *Rapala iarbus* collecting nectar, i. Hesperiid butterfly, *Hasora chromus* collecting nectar. @Prof. Jacob Solomon Raju Aluri.

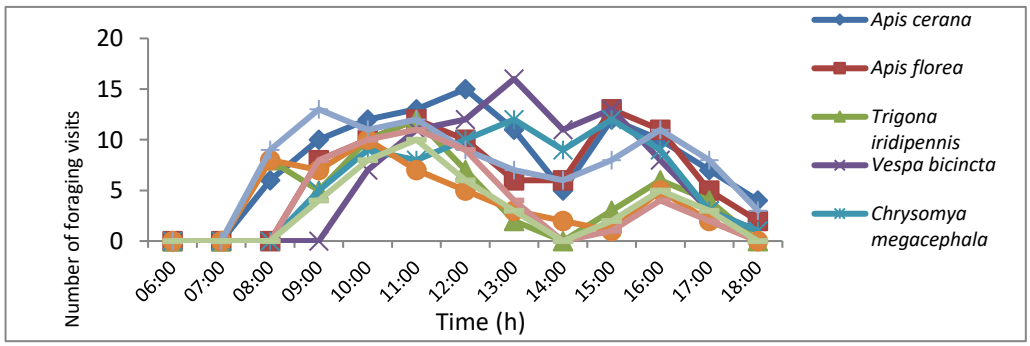

Figure 6 Hourly foraging activity of bees, wasps, flies and butterflies on *Litsea deccanensis*

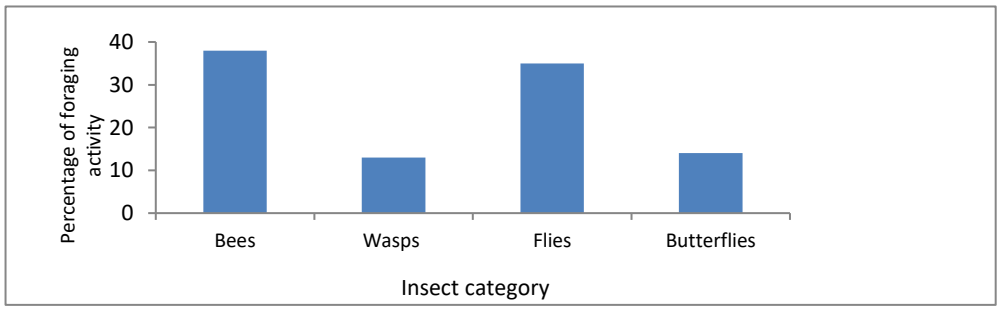

Figure 7 Percentage of foraging activity of bees, wasps, flies and butterflies on *Litsea deccanensis*

Table 7 Pollen recorded in the body washings of insects on staminate and pistillate trees of *Litsea deccanensis*

Insect species	Sample size (N)	Number of pollen grains		
		Range	Mean	S.D
Apis cerana	10	68-366	193.6	83.1
Apis florea	10	73-291	186.5	66.9
Trigona iridipennis	10	49-188	118.7	37.9
Vespa bicincta	10	22-71	46.8	14.1
Chrysomya megacephala	10	11-69	39.7	15.1
Sarcophaga sp.	10	19-63	38.9	12.0
Eristalinus arvorum	10	27-84	58.8	15.4
Rapala iarbus	10	16–57	39.4	10.2
Hasora chromus	10	13-49	35.6	9.4

All insects easily landed on the flat-topped pseudo-umbels and foraged the florets one after the other. A single visit by insects enabled them to collect the forage from several florets and several umbels with reduced flight distance and search time. The occurrence of several involucral buds at a single point appeared to be highly rewarding in a single visit by the insects. These insects foraged on trees of both sexes without any discrimination and contributed to the promotion of pollination rate. The insects collecting only nectar moved fast from one umbel to another on the same tree and to other nearby trees in quest of more nectar. As most umbels were either depleted or emptied of nectar due to nectar-feeding activity by thrips, the insects made quick visits to several umbels on the same and different trees in search of nectar increasing pollination rate in pistillate trees. Some bees collected only pollen, some others only nectar and still some others both pollen and nectar in the same foraging bout. The pollen collecting bees tended to stay more time on the same plant than other categories of bees. These differential forage collecting behaviours collectively drove them to visit both staminate and pistillate trees; as a result, they effected pollination in pistillate trees. The syrphid fly, *E. arvorum* visited the umbels in swarms and made frequent visits to the trees of both sexes in search of both floral rewards effecting pollination. Therefore, all insect foragers contributed to pollination suggesting that the tree species has a generalist pollination syndrome and is polyphilous.

Further, the staminate trees present a massive number of florets, each with several protruded stamens daily. The initially semi-wet pollen becomes dry and powdery later which then easily liberated into the air especially during noon-time. The occurrence of both staminate and pistillate trees close to each other facilitated the pollen transfer between sexes. Therefore, this tree species is designated as ambophilous involving entomophily and anemophily.

Table 8 Number of fruits/seed set rate per involucral umbels in pistillate trees of *Litsea deccanensis*

Natural fruit/seed set	Involucral umbel													
Number of fruits/seeds produced	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. of fruits/seeds recorded	**108**	**101**	**55**	34	7	7	1	3	0	0	0	0	1	1
Percentage **(%)**	**34**	**32**	**17**	11	2	2	0.3	1	0	0	0	0	0.3	0.3

N = 318, Range = 1-14, $\bar{x}$ = 2.26, S.D = 1.35

Table 9 Natural fruit and seed set rate in *Litsea deccanensis*

Tree number	Number of florets sampled	Number of florets set fruit	Fruit set rate **(%)**	Seed set rate **(%)**
1	35	4	11.4	11.4
2	48	5	10.4	10.4
3	44	7	15.9	15.9

4	39	4	10.2	15.3
5	37	6	16.2	16.2
6	53	5	9.4	9.4
Total	256	31	12.1	12.1

Figure 8 *Litsea deccanensis*: a. 1-fruited involucral bud, b. 2-fruited involucral bud, c. 3-fruited involucral bud, d. 4-fruited involucral bud, e. 5-fruited involucral bud, f. 6-fruited involucral bud, g. 7-fruited involucral bud, h. 8-fruited involucral bud, i. 13-fruited involucral bud, j. & k. Seedlings, l. Root sucker growing into new shoots. @Prof. Jacob Solomon Raju Aluri.

Fruiting ecology

In pistillate trees, a single involucral unified flower consisting of several florets produce 1-14 fruits but the percentage of production of 1 or 2 fruits is the highest (Table 8; Figure 8a-i). Natural fruit set varied from 9.4 to 16.2% on different trees (Table 9; Figure 5). Fruit set and seed set rates were the same pistillate florets produced invariably produced a single ovule per floret. Fruits matured within three weeks. They are 1-seeded, 10-15 mm diameter fleshy berries with persistent apiculate apex seated on flat disc and supported by enlarged pedicels. They are initially green with white dots and purple to black when ripe, and aromatic when crushed. Their surface is glabrous, glossy, and sometimes glaucous. The seeds are brown with dark spots and 5-7 mm in diameter. The Indian Giant Squirrel, *Ratufa indica* was the sole animal which was feeding on the fruits regularly during October-February. It did not always eat the fruits right away. Sometimes, it carried them to a far location where it ate subsequently. The seeds excreted by this squirrel remained in their original state but they are softened. This squirrel with its swift movements excretes and disperses the seeds across the forest. Naturally, mature fruits fell to the ground and seeds were exposed after the decomposition of fruit pulp. Field studies showed that the tree is propagated by vegetative and seed modes. Vegetative means included stem-cuttings and root-suckers (Figure 8 i). Seeds germinated only during rainy season irrespective of the time of fruit dispersal (Figure 8 j,k). In the natural habitat, seed germination rate is 9% only.

4. DISCUSSION

Litsea deccanensis is a fast growing semi-evergreen dioecious species with staminate and pistillate individuals with a brief flowering period during July-August in the Eastern Ghats. It is pertinent to mention that a very small percentage of umbels, especially solitary ones produce fertile hermaphroditic flowers in staminate trees. But, pistillate trees characteristically produce pistillate flowers only. Rohwer (1993) mentioned that Lauraceae members are probably obligate out-breeders but there are no systematic studies on individual species with reference to sexual reproduction. In the present study, the involucral bracts in *L. deccanensis* act as unified flowers consisting of several florets with both male and female organs but functionally each floret is functionally unisexual on any given individual and hence it typifies dioecious sexual system evolved for obligate out-breeding system. The schedules of stigma

receptivity and anther dehiscence promote out-crossing rate. Sex ratio biased in favour of staminate trees additionally promotes out-crossing by increasing pollen transfer to pistillate trees via insects. The presence of many yellow coloured multi-floreted pseudo-umbels each day adds more attraction to insects. One-time nectar secretion by specialized glands in both staminate and pistillate florets is probably an evolved character to discourage repeated visits to the same florets and promote visits between staminate and pistillate trees by insects to maximize fruit/seed set. Kubitzki and Kurz (1984) and Rohwer (2009) reported such a nectar secretion pattern in most Lauraceae species which produce bisexual flowers. In these species, the flowers open twice in their life time, the first time anthesis represents female phase during which staminodial glands secrete nectar once and the second time anthesis represents male phase during which staminal glands secrete nectar once.

Nalini and Nathaniel (2000) reported that Lauraceae members are pollinated by a wide variety of generalist insects such as Hymenoptera, Diptera and Lepidoptera. Soubadra Devy and Davidar (2006) noted that *Litsea* sp. is dioecious and pollinated by social bees. Ci et al. (2008) noted that *L. szemaois* is insect-pollinated. House (1989) reported that *L. leefeana* with unspecialized flowers is predominantly pollinated by Diptera. Corlett (2001) reported that *L. glutinosa* is overwhelmingly visited by *Apis cerana* but it paid most visits to male flowers than female flowers. In this study, the floral characters of *L. deccanensis* such as light yellow shallow staminate and pistillate florets with slight foetid smell and yellow nectar glands, well exposed nectar and actinomorphic symmetry constitute myophilous pollination syndrome according to the floral traits described for fly-pollination by Faegri and van der Pijl (1979) and Bertin (1989). In line with this, *L. deccanensis* is pollinated principally by flies although it is pollinated also by other insects. The functionality of myophily in this tree is also in agreement with Armstrong (1979) who stated that fly-pollinated flowers are shallow and unspecialized due to which flies access the nectar with great ease. Myophily and hymenopterans pollination evidenced in *L. deccanensis* has been reported to be a dominating trait among unspecialized entomophilous plants (Jones and Crome, 1990). Therefore, *L. deccanensis* with unspecialized flowers is principally myophilous and pollinated additionally by other insects. Thrips reduce the standing nectar crop significantly but this situation drives the pollinators to increase foraging visits to both staminate and pistillate trees due to which out-crossing rate gets enhanced. But, the short flowering season is disadvantageous for the tree to maximize its fruit and seed set rate. The recorded fruit set in pistillate trees indicates that myophily is not an efficient pollination syndrome.

In Lauraceae, fruit dispersal by frugivorous birds and/or animals is reported to be common (Rohwer 1993). Ornithochory is reported in *Litsea cubeba* (Sri-ngernyuang et al. 2003), *L. wightiana* and *L. mysorensis* (Ganesh and Davidar, 2001) while barochory is reported in *L. szemaois* (Ci et al. 2008). In *L. deccanensis,* barochory involving fruit dispersal by gravity and zoochory involving fruit dispersal by the Indian Giant Squirrel, *Ratufa indica* are functional. Future studies are warranted to study the fate of seeds dispersed by the squirrel as compared to seeds that simply fall from the parent tree. Tiwari et al. (2015) noted that *L. glutinosa* is able to reproduce vegetatively from root-suckers. In this study, *L. deccanensis* propagates by stem-cuttings, root suckers as well as by seeds. Propagation by seed is the only means through which genetic variation occurs and it is an essential mode of propagation for the survivability and sustainability of populations of this tree species.

5. CONCLUSION

Litsea deccanensis is a semi-evergreen dioecious species which flowers during wet season. Dioecy is represented by staminate and pistillate umbels/involucral bracts/florets. But, staminate trees produce a negligible percentage of bisexual flowers in which both male and female organs are functional and produce fruit if pollinated and fertilized. Both staminate and pistillate florets produce nectar which is utilized by different insect species of which flies play a prominent role. Fruit set rate is equal to seed set rate due to the production of a single ovule per ovary in pistillate florets. Barochory and zoochory are the modes of fruit dispersal. In addition to seed mode of propagation, the tree species also propagates by stem-cuttings and root suckers. Therefore, the information reported in this paper forms an important knowledge base for further studies in the direction of restoring the population size of *L. deccanensis*.

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Author's contributions

All three authors contributed equally.

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