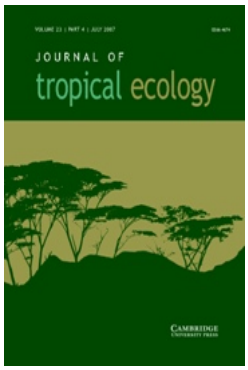

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SHORT COMMUNICATION

Pollination ecology of cardamom (*Elettaria cardamomum*) in the Western Ghats, India

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Heterogeneous agroforestry systems play an important role in maintaining animal pollinator diversity (Klein *et al.* 2003, Perfecto *et al.* 1996), most likely by extending floral resources in lean periods. An understanding of the mutualistic relationship between flower-visiting insects and crop species in such agroforestry systems (Kearns *et al.* 1998), particularly on the diversity of pollinator species, their spatio-temporal variations, foraging behaviour (Cunningham 2000, Greenleaf & Kremen 2006, Klein *et al.* 2003) and their pollination efficiency (Motten *et al.* 1981), is important as they are some of the crucial biological predictors of pollination success.

Cardamom (*Elettaria cardamomum* (L.) Maton, Zingiberaceae), an understorey herb species of Indian origin, is cultivated extensively in the high-altitude hilly areas of the Western Ghats of Kerala, Tamil Nadu and Karnataka States of peninsular India for its fruits. The plantations are traditionally raised in low-intensity agroforestry systems under the shade of a forest canopy or under the canopy of older multistoreyed agroforestry systems dominated by betel nut (*Areca catechu*). As the fruit is the economic product of cardamom, fruit development is dependent on effective pollination. We studied pollination ecology of cardamom in three locations covering the cardamom-growing belt in the Western Ghats of India (Table 1). Our focus was on the following questions: (1) Which species are the pollinators? (2) What are their foraging patterns and how are they related to successful pollination? (3) Are there any temporal or spatial shifts in pollinators? (4) What is the breeding system of cardamom?

More than 50 clumps of cardamom plants were thoroughly examined in each of the three study sites. The study was conducted from 13 May 2006 to 31 August 2006 in different locations. However, a pilot survey of floral visitors and pollinators was made at Sringeri during peak flowering in 2005.

At Sringeri, observations on floral visitors and pollination efficiency were made intensively during the three stages of flowering: early (May), peak (June) and late flowering (July). The observations in Kambalakkadu were carried out in May (peak flowering) and June (late flowering) as the flowering at this site was early, coinciding with the onset of early south-west monsoon. At Nalmukku we carried out observations only to identify floral visitors and pollinators in the month of August (late flowering).

We selected observation sites randomly in the plantation to record floral visitors in such a way that 25–50 freshly opened flowers were clearly visible from the observation spot. In all the study sites the observations were made between 06h30 and 14h00 continuously without any break. The visitation rate, foraging time per flower and foraging behaviour of the floral visitors were recorded. For analyses we divided the observation period into 2-h time intervals (06h00–08h00, 08h00–10h00, 10h00–12h00, and 12h00–14h00). The visitors were either identified to species in the field wherever possible, or collected them using an aspirator for identification. The insects were immobilized using ethyl acetate, and observed under the stereomicroscope to study pollen load. We distinguished pollinators from floral visitors on the basis of (1) their foraging pattern (bringing the visitor in contact with the anther and the stigma), (2) pollen load on their body and (3) pollen load in the stigma cup after their visit to virgin flowers. We compared the efficiency of foraging habit of one of the major pollinators in effecting pollination. For this, the type of foraging in each flower was recorded and the flowers were collected soon after the visits, and stigmas were studied for pollen load. To study the efficiency of open pollination under field conditions,

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Table 1. Physical and agronomic features of study sites.

	Study sites (State)		
	Sringeri (Karnataka)	Kambalakkadu (Kerala)	Nalmukku (Tamil Nadu)
Location	13°29.332′N, 75°11.891′E	11°40.808′N, 76°4.694′E	8°33.182′N, 77°21.882′E
Altitude (m asl)	626	782	1268
Forest type	Evergreen	Evergreen	Evergreen
Protection level	Revenue forests	Wildlife sanctuary	Wildlife sanctuary
Shade of plantation	*Areca catechu*	*Areca catechu*	Evergreen forest tree species
Cardamom variety	Native	Mysore	Mysore
Panicle type	Spreading at ground level	Erect	Erect
Domesticated bee hives	Absent	Present	Absent
Plantation type	Farmer owned and managed	Farmer owned and managed	Abandoned (>15 y) after the area was declared as a protected area

we collected flowers randomly from different plants at 14h00 and scored their stigmas for the presence of pollen. To study the breeding system, manually pollinated and bagged flowers were allowed to develop into fruits, and the details of fruit and seed set were analysed. The quantitative data were analysed by using Kruskal–Wallis rank ANOVA. The pair-wise comparisons were made using Mann–Whitney U-test. Analyses were performed using STATISTICA (StatSoft, Inc).

The details of floral morphology of cardamom are described in detail by Gregory (1935). Floral anthesis in all the study sites starts around 05h30 and most of the flowers are fully open by 06h30. The solitary anther dehisces by longitudinal slits soon after anthesis exposing a large mass of white pollen grains. The flowers remain open only for a day and start senescing by 17h00.

A total of 18 species of animal visited the flowers of cardamom across the three study sites (Table 2). The species composition of floral visitors varied between sites. Many species were exclusive visitors to an individual study site. However, the honey bee species, *Apis cerana,* was the common visitor in all the three study sites, although it was absent in the early flowering season at Sringeri. Eleven species each visited cardamom flowers in Sringeri and Kambalakkadu; this, however, was limited to only six species in Nalmukku. Among the 18 floral visitors, only three, *Apis cerana*, *Trigona iridipennis* and *Ceratina hieroglyphica*, carried pollen load on their body and came in contact with the stigma. The remaining visitors did not carry pollen load and did not make contact with the stigma.

We studied the activity of *T. iridipennis* and *A. cerena* through the day. Kruskal–Wallis rank ANOVA showed that the differences in the *T. iridipennis* and *A. cerana* bee visits and the foraging time per flower were not significant across time intervals in Sringeri. However, at Kambalakkadu the differences in the *A. cerana* bee visits

Table 2. Floral visitors of cardamom in three study locations (number of visits h^{-1}).

Flower visitors		Study locations		
Species	Family	Sringeri	Kambalakkadu	Nalmukku
Bees				
Amegilla sp.	Anthophoridae	2.46	7.47	
Apis cerana F.	Apidae	8.62	18.5	20.4
Ceratina hieroglyphica Smith	Apidae	2.30		1.28
Halictid bee	Halictidae		0.71	
Megachila sp.	Megachilidae	0.64	2.71	8.0
Nomia sp.	Halictidae	0.57	2.28	2.14
Trigona iridipennis Smith	Apidae	20.32	0.09	
Xylocopa verticalis Lepel.	Xylocopidae		2.0	
Flies				
Calliphorid fly	Calliphoridae		1.14	
Hover fly	Syrphidae		1.38	
Butterflies				
Papilio polymnestor Cramer	Papilionidae	0.03		
Celaenorrhinus leucocera Kollar	Hesperiidae	0.01		
Papilio helenus L.	Papilionidae	0.25		
Notocrypta curvifascia Felder & Felder	Hesperiidae			1.14
Borbo cinnara Wallace	Hesperiidae	0.33		
Birds				
Sunbird	Nectariniidae		0.57	2.85
Other visitors				
Earwig	Forficulidae		2.0	
Anoplolepis gracilipes Smith	Formicidae	0.5		

Observation period: Sringeri, N = 56 h; Kambalakkadu, N = 21 h; Nalmukku, N = 7 h.

Table 3. Pollination efficiency of *Trigona iridipennis*, *Apis cerena* and under open field conditions.

Mode of pollination Study site Month	N	% pollinated
Open		
Sringeri		
May	15	53.3
June	95	70.5
July	63	69.8
Wayanad		
May	50	86
June	125	40
T. iridipennis pollen collecting		
Sringeri		
May	18	83.3
June	22	95.5
A. cerana pollen collecting		
Sringeri		
June	43	46.5
A. cerana + *T. iridipennis* pollen collecting		
Sringeri		
June	22	100
A. cerana nectar collecting		
Sringeri		
June	31	0
Wayanad		
June	34	5.9

(n = 38, KW H = 9.80, df = 2, P = 0.007) and foraging time per flower (n = 38, KW H = 10.9, df = 2, P = 0.004) were highly significant among time periods.

At Sringeri, *T. iridipennis* was active in all the three periods of flowering. The visits were highest during the peak flowering, and were least in late flowering. The differences in the bee visits (n = 83, KW H = 20.2, df = 2, P = 0.0001) and foraging time per flower (n = 83, KW H = 26.3, df = 2, P = 0.0001) across flowering seasons were significant.

We confirmed the relative importance of the frequent flower visitors, stingless bee *T. iridipennis* and honey bee *A. cerena* in pollination through studies of pollen load in the stigma of flowers exclusively visited by them. As the visits of a solitary bee *C. hieroglyphica* started much later than the visits by the other two bee species and tended to visit the flowers already visited by other species, we could not study its involvement in pollination thoroughly. Even if it can be a pollinator, the frequency of its visit was very low when compared with the other two bee species (Table 2); we, therefore, considered its contribution to pollination efficiency of cardamom as negligible.

Trigona iridipennis was a far more efficient pollinator than *A. cerena*. During the early period of flowering at Sringeri, over 83% of *T. iridipennis*-visited flowers were pollinated; the efficiency increased to 95.5% in the peak of flowering. There were hardly any *A. cerana* visits during the early flowering at Sringeri. Even during the peak flowering period *A. cerena* was relatively less efficient in pollination; only 46.5% of *A. cerena*-visited flowers were pollinated (see Table 3 for complete statistics). The pairwise comparison, however, showed that the proportion of the pollinated flowers due to *T. iridipennis* was significantly higher than that due to *A. cerana* visits for pollen foraging (Mann–Whitney U-test, U = 241, P = 0.001).

During our observations we could identify a number of flowers which were visited by *T. iridipennis* in the early morning followed by *A. cerena* visits in a later period and vice versa. We marked such flowers and studied their pollination efficiency. The pollination efficiency almost doubled when *A. cerana*-visited flowers were followed by the *Trigona* visit; the difference in the proportion of the pollinated flowers was highly significant (Mann–Whitney U-test, U = 220, P = 0.0004). However, when the *T. iridipennis*-visited flowers were followed by the pollen foraging trips of *A. cerana*, the proportion of the pollinated flowers was increased only marginally (4.5%) and the difference was not statistically significant.

Unlike *T. iridipennis*, which forages exclusively for pollen, *A. cerana* forages for pollen as well as nectar. This suggests that *T. iridipennis* may not be the co-evolved pollinator of cardamom. At Sringeri and Kambalakkadu we monitored the flowers visited by *A. cerana* only for nectar, and tagged such flowers and observed their stigmas for pollen load. At Sringeri 100% of the *A. cerena*-visited flowers for nectar (n = 31) remained unpollinated, while in Kambalakkadu, only about 5% of the flowers (n = 34) were pollinated.

At Sringeri over 50% of the flowers showed pollination in the early flowering stage of cardamom under open pollination; this increased to about 70% during the peak and late flowering. However the differences between the three seasons were not statistically significant (n = 173, KW H = 1.82, df = 2, P = 0.40). Open pollination efficiency at Kambalakkadu was high at the peak of flowering (May, 86%), but halved in the late flowering season (June, 40%); this could be in response to the change in the foraging habit of *A. cerena*, as the bees spent most of their visits for nectar collection during late flowering. However, the difference in the proportion of pollinated flowers across seasons was statistically significant (Mann–Whitney U-test, U = 1925, P = 0.00007).

There was hardly any natural autogamy; only about 13% of bagged flowers set fruits and the average seed number per flower was very low (1.0 ± 0.50 SE, N = 22), which was 69% (seed number = 10.3 ± 1.52, N = 29) and 61% (seed number = 10.2 ± 1.68, N = 28) in self- and cross-pollinated flowers respectively; however, the difference was not statistically significant. The results clearly show that the species is self-compatible.

Our studies highlight temporal and spatial shifts in pollinator community and pollination efficiency of cardamom. So far only domesticated honeybee species (*Apis cerena, A. dorsata* and *A. florea*) have been reported as the pollinators of cardamom (Klein *et al*. 2007). Our study, however, documented a wild stingless bee, *T. iridipennis*

as an additional pollinator for cardamom. At Sringeri, *T. iridipennis* was the only principal pollinator during the early flowering and was later supplemented by *A. cerena*. At the other two study locations, *A. cerena*, an important crop pollinator species of India, was the only abundant pollinator. *A. dorsata*, which is reported to be one of the main pollinators of cardamom at other locations in the Western Ghats (Belavadi *et al.* 1997, Crane 1991, Joseph & Mohandas 1985), was not a flower visitor in any of our study sites. Thus, the pollination system in cardamom is dynamic and principal pollinator(s) vary according to local conditions. However, as both cardamom and *A. cerena* have a long history of domestication, it is not surprising that there are site variations in pollination systems. The study, however, raises deep concern on the absence or relatively very few visits of *T. iridipennis*, in the other two study sites, and assumes that the species must have gradually been eliminated in the competition with the aggressive domesticated honey bees. The study thus adds to the growing evidence for the role of wild stingless bees (Heard 1999, Slaa *et al.* 2006) as important crop pollinators in the tropics.

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