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Short Note

Flower Visitors of *Parkia sumatrana* (Leguminosae) in Northeastern Thailand

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Plants that strongly rely on specific animals for their pollination have a characteristic flower shape, color, or odor to attract the pollinating target animals. These characteristics are commonly observed beyond phylogenetic relationships and are categorized as a pollination syndrome in each pollinator group[1]. However, some exceptions have been reported,[2,3] and it is difficult to determine the pollinator group based only on floral characteristics. Therefore, the observation of flower visitor behavior is important to determine pollinators.

Parkia is a genus of tropical tree that includes more than 30 species globally, most of which reside in South America[4]. Species in Southeast Asia are economically important because their seeds are used as food in this area. The *Parkia* inflorescence is ball shaped and hangs from a branch by a long peduncle (Fig. 1). The flower blooms at night, is yellow in color, and emits a strong odor. These characteristics are considered to fit into the bat-pollination syndrome, and some species are known to be pollinated by bats[5,6]. *Parkia timoriana*, distributed in the tropical rainforests of Southeast Asia, is self-incompatible, and bears fruits when bats visit; whereas insects, such as bees, do not pollinate the flower[6]. In addition, bats have been identified as important pollinators in several species of *Parkia* in South America[7]. Both bats and bees contribute to the pollination success of *P. biglobosa* in Africa[8], and bats and lemurs (*Eulemur macaco)* pollinate *P. madagascariensis* in Madagascar[9].

Parkia sumatrana is distributed in the evergreen forests of Southeast Asia and it is the only *Parkia* species found inland in the Indo-china peninsula[4]. Hopkins (1994) categorized *Parkia* species into three inflorescence types depending on the shape of the flower, and *P. sumatrana* was classified into the *P. versteeghii*-type, which has flowers with long staminodes (Fig. 1). The aim of this study was to identify the flower visitors of *P. sumatrana*, and to describe their visiting behavior in northeastern Thailand.

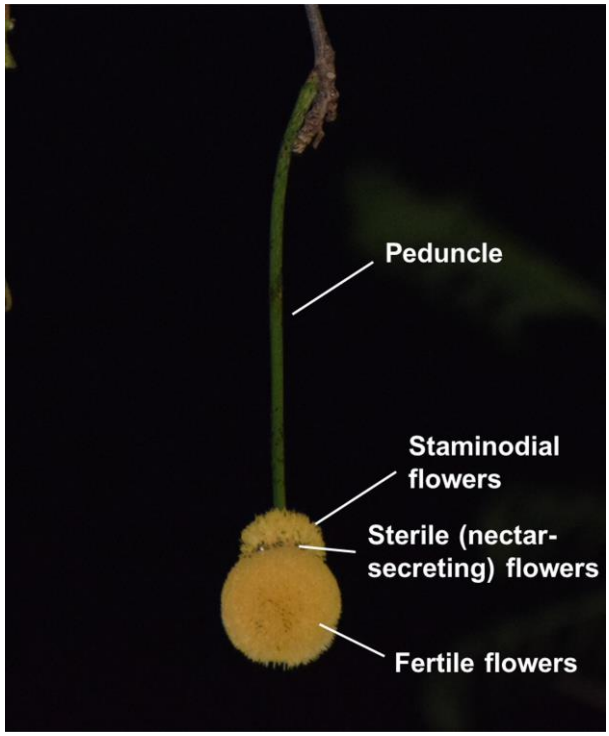

FIGURE 1. Inflorescence of *Parkia sumatrana*

This study was conducted in the Sakaerat Biosphere Reserve (14°30′35″ N 101°55′49″ E). The headquarters stand between a dry evergreen forest dominated by *Hopea ferrea*, and a dry dipterocarp forest dominated by *Dipterocarpus intricatus*, *Shorea obtuse*, *S. talura* and *Pterocarpus macrocarpus*. One individual of *P. sumatrana* growing at the boundary between a dry evergreen forest and the headquarter area of the Sakaerat Environmental Research Station was observed. This plant was distributed scattered in the dry evergreen forest in this area. The study was conducted at the end of the dry season and no rain was recorded during the observation. The annual mean temperature in this area is 26°C; the lowest temperature during our study was 20°C and the highest was 40°C.

The observation was performed for 10 d, 7 d, and 4 d in March 2016, 2017, and 2019, respectively during the flowering season of this species in this area. Night observations were conducted using binoculars with light from a streetlamp, and a flashlight was employed every 10 minutes to confirm the species of flower visitors. The target of this observation was vertebrates. The observed number of inflorescences was 58 in 2016, 109 in 2017, and 24 in 2019, and the total observation time was 121 h and 5 min (Table 1). In addition, insect visitors were observed in the daytime on the 10th to 11th, 13th to 14th, and 16th to 17th of March in 2016. Four inflorescences were checked

TABLE 1. Observation time in each 3-h period in each study year

Time	2016	2017	2019	Total
00:00-03:00 h	4h 10m	6h 25m	3h 15m	13h 50m
03:00-06:00 h	4h 25m	11h 35m	2h 35m	18h 35m
06:00-09:00 h	5h 56m	4h 55m	1h 30m	12h 21m
09:00-12:00 h	2h 27m	0	4h 05m	6h 32m
12:00-15:00 h	2h 16m	0	2h 05m	4h 21m
15:00-18:00 h	3h 33m	0	2h 30m	6h 03m
18:00-21:00 h	11h 29m	7h 05m	5h 41m	24h 15m
21:00-24:00 h	11h 22m	19h 25m	4h 21m	35h 08m
Total	**45h 38m**	**49h 25m**	**26h 02m**	**121h 05m**

TABLE 2. Total number of observed visited inflorescences by each flower visitor.

Species name	Common name	Total number of visited inflorescences
Nycticebus bengalensis	Bengal slow loris	533
Hylopetes sp.	Flying squirrel sp.	244
Callosciurus finlaysonii	Finlayson's squirrel	100
Cinnyris jugularis	Olive-backed sunbird	1
Apis sp.	Honeybee sp.	+
Apidae sp.	Apidae sp.	+
Meliponini sp.	Stingless bees sp.	+
	Butterfly sp.	+
	Moth sp.	+

+: Recorded as a flower visitor but the number of individuals was unknown.

every hour from 5:00–18:00 h and the number of insects was recorded.

The staying duration on an observed inflorescence, the number of contacted inflorescences per visit, and the handling time, which is the amount of time that the animals held the inflorescence or peduncle to lick on the nectar, were recorded and compared by Tukey's honestly significant difference test. The statistical test was conducted using the R version 3.5.0[10] software.

The Bengal slow loris *Nycticebus bengalensis*, flying squirrel sp. *Hylopetes* sp., Finlayson's squirrel *Callosciurus finlaysonii*, and the olive-backed sunbird *Cinnyris jugularis* were recorded as vertebrate flower visitors of *P. sumatrana* (Table 2, Fig. 2a–c). The olive-backed sunbird was observed only once; it perched on an inflorescence and pecked at the flowers. Bengal slow lorises had the greatest number of visits to the inflorescences (Table 2).

FIGURE 2. Flower visitors of *Parkia sumatrana*. a. Bengal slow loris *Nycticebus bengalensis*, b. flying squirrel *Hylopetes* sp., c. Finlayson's squirrel *Callosciurus finlaysonii*, d. Apis sp., e. stingless bee, and f. butterfly.

Among them, Bengal slow lorises and flying squirrels were nocturnal, whereas the others were diurnal visitors (Fig. 3). Bengal slow lorises and flying squirrels intermittently visited inflorescences at night, but flying squirrels were observed over a longer duration (18:00–4:00 h) than slow lorises (19:00–3:00 h) (Fig. 3). Finlayson's squirrels visited around sunset and sunrise (Fig. 3).

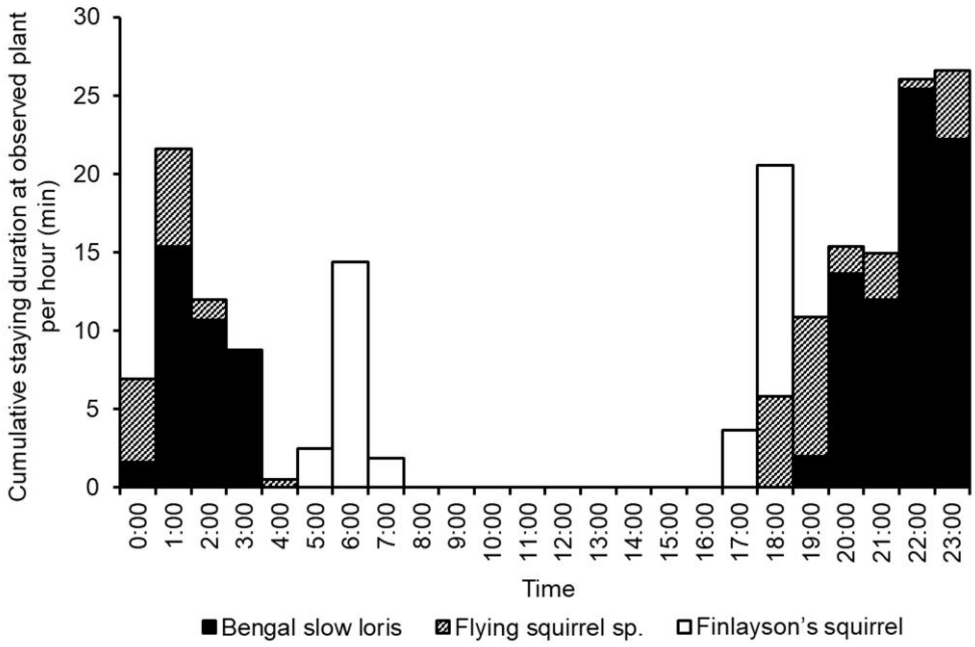

FIGURE 3. Visiting time and staying durations of the mammalian flower visitors

Bengal slow lorises stayed significantly longer ($p < 0.001$) at the observed tree [38.3±33.7 (mean±SD) min (n=25)] than the other two mammals: flying squirrels ([8.1±5.6 s (n=31)] and Finlayson's squirrels [6.5±4.2 s (n=26)] (Fig. 4a). In addition, Bengal slow lorises visited significantly ($p < 0.001$) more inflorescences per stay (22.2±22.2 inflorescences, n=24) than the flying squirrels or Finlayson's squirrels at 9.4±7.7 (n=26) and 4.2±3.7 (n=24) inflorescences, respectively (Fig. 4b). These three mammals clasped an inflorescence and licked on the nectar-secreting flowers, while the fertile flowers attached to their forelimbs, head, and abdomen. The average handling time per inflorescence was 29.7±18.7 s (n=391) for Bengal slow lorises, which was significantly longer ($p < 0.001$) than that for flying squirrels and Finlayson's squirrels at 12.0±14.2 s (n=189) and 10.5±12.2 s (n=70), respectively (Fig. 4c).

Honeybees, stingless bees, and butterflies were also observed to visit *P. sumatrana* (Table 2, Fig. 2d–f). Bees visited fertile flowers and nectar-secreting flowers. They did not visit inflorescences before 5:00 h, and the largest number of them arrived near 6:00 h (Fig. 5). An average of 1–3 individuals visited from 8:00–18:00 h (Fig. 5).

Fruit was observed in 2019, but not in the other two years of this study. Two of the observed inflorescences bore fruit, and both of them were visited by Bengal slow lorises and *Hylopetes* sp. Insect observations were not conducted on these inflorescences.

Most *Parkia* species are pollinated by fruit bats[11], but no fruit bats visited *P. sumatrana* in this study. Seven herbivorous

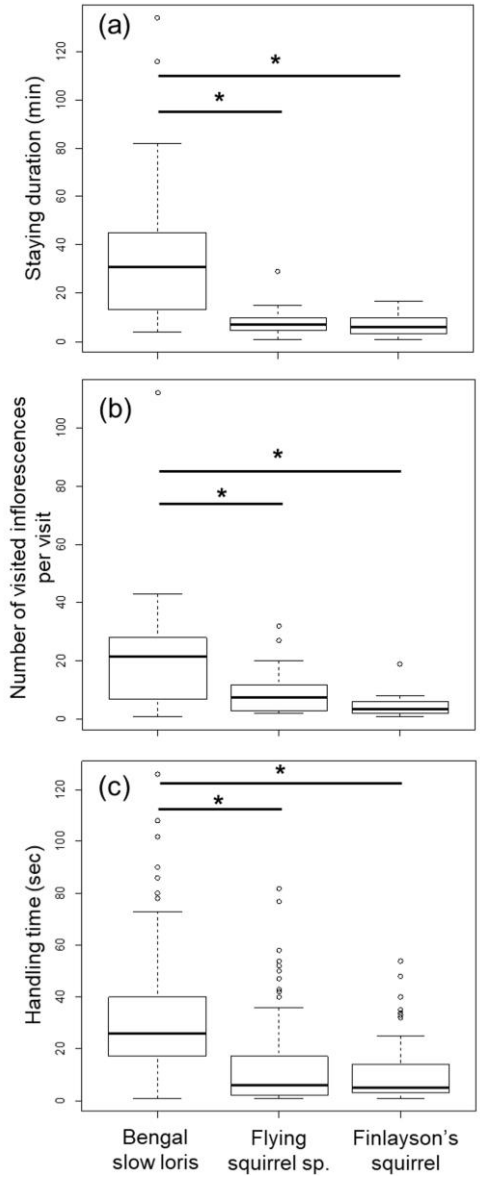

FIGURE 4. Comparisons of the staying duration (a), number of visited inflorescences per visit (b), and handling time per inflorescence (c) on the observed *P. sumatrana* tree. Boxes indicate the median with first and third quartiles. Whiskers indicate data points located within a range of 1.5 times the respective interquartiles. Open circles indicate outliers. Asterisks indicated a significant difference ($p < 0.001$, Tukey honestly significant difference test).

bats were recorded at the study site[12], and at least one species visited *Mucuna macrocarpa* (Fabaceae) flowers to feed on nectar in February and March 2018 at the same study site[13], confirming that fruit bats were present in the area, but they chose not to visit *P. sumatrana* or they are rare in this area.

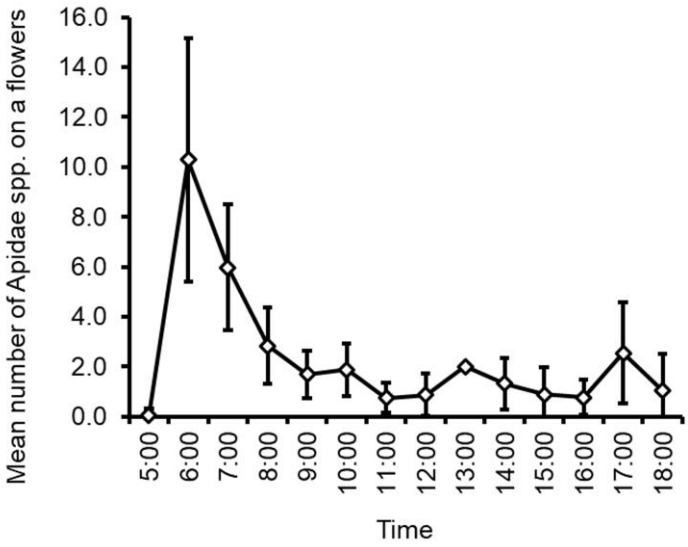

FIGURE 5. Visiting time of bees. Error bars indicate SD.

Bengal slow lorises and flying squirrels visited inflorescences at night, and Finlayson's squirrels and bees were recorded as diurnal visitors. Although bees have been recorded as pollinators of *Parkia* spp.[8,14], non-flying mammalian visitors have not previously been reported as flower visitors to *Parkia*. Observation of these mammals and bees in this study revealed that pollen grains adhered to their bodies; therefore, *P. sumatrana* may be pollinated by non-flying mammals and bees.

Among the flower visitors, Bengal slow lorises showed the greatest number of visited inflorescences, the longest staying time, the largest number of contacted inflorescences per visit, and the longest handling time. However, long stay and handling times are not always necessary for effective pollination, because they increase the possibility of self-pollination and reduce the chance of cross-pollination. As for Finlayson's squirrel, although the staying duration was shorter than that of slow lorises, the squirrel's home range may be too small to promote cross pollination. Although the actual home range size of this species is not known, the *Callosciurus* squirrel, another diurnal and similar-sized squirrel, has a home range of only 0.3–2.7 ha[15,16]. In contrast to slow lorises and squirrels, flying squirrels stayed for a shorter duration, but the home range size of flying squirrels is generally larger than that of *Callosciurus* squirrels. Thus, flying squirrels could be one of the important pollinators. Flying squirrels have not been recorded as pollinators, but this group has the potential to be an important pollinator for *Parkia* in Asia.

Mammals may visit inflorescences to feed on nectar. The main feeding habit of Bengal slow lorises is exudativory and nectar feeding is uncommon[17,18,19]. The main foods of flying squirrels (*Hylopetes* spp.) are fruits, including cultivated fruits, and

flower-feeding is uncommon in this group as well[20,21,22]. *Callosciurus* squirrels including Finlayson's squirrels feed on nectar and some species are important pollinators for certain plants[13,23,24]. The relative importance of *P. sumatrana* as food for these mammals remains to be ascertained. This study was conducted at the end of dry season when food resources are poor, and liquid food may be important when the animals' normal provisions are depleted.

The sample size of this study is small and the reproductive system of this plant is still unclear. The possibility of the self-fertilization should be still considered. Thus, expanded studies, including enlarging the sample size and conducting bagging experiments, are needed to determine the pollination system of this species.

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