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SHORT COMMUNICATION

Effect of ingestion by two frugivorous bat species on the seed germination of *Ficus racemosa* and *F. hispida* (Moraceae)

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Frugivorous bats are important seed dispersers for many plant species (Cox *et al.* 1991, Fleming & Heithaus 1981, Hodgkison *et al.* 2003a, McConkey & Drake 2006, Nyhagen *et al.* 2005, Utzurrum 1995). They regularly consume figs in the wild (Fujita & Tuttle 1991, Kalko *et al.* 1996, Shilton *et al.* 1999). Various species of pteropodid bats have been reported foraging on the fruits of more than 30 fig species in tropical and subtropical Asia, Africa and Australia (Bhat 1994, Fujita & Tuttle 1991, Marshall & McWilliam 1982, Thomas 1984). Food transit times in frugivorous bats are relatively rapid; generally less than 30 min (Laska 1990, Tedman & Hall 1985). Several studies have demonstrated that seed germination was either enhanced or unaffected after passage through the digestive tract of bats (Figueiredo & Perin 1995, Fleming & Heithaus 1981, Lieberman & Lieberman 1986).

In Xishuangbanna, two fig species (*Ficus hispida* L. and *Ficus racemosa* L.) are distributed widely and are thought to be key species in the rebuilding of degraded habitats (Peng *et al.* 2005). Two frugivorous bat species (*Rousettus leschenaulti* Desmarest and *Cynopterus sphinx* Vahl) are common and widely distributed in Xishuangbanna and fruits of *Ficus hispida* and *F. racemosa* are consumed heavily by these two bats (Tang *et al.* 2005). When they feed on the fruits of these two fig species, a proportion of seeds was swallowed and excreted through the digestive tract as scats and others were spat out in compact fibrous pellets (ejecta). In this study, we investigate the effect of bat feeding behaviour on the seed germination of two common fig species and compare characteristics of germination for different treatments. We want to know if foraging behaviour significantly affects seed germination.

We captured bats using mist nests between 1 and 7 July 2005 in a protected area of forest (21°55′N, 101°16′E, 550 m asl) in the Xishuangbanna Tropical Botanical Garden (XTBG), in Yunnan Province of south-west China. Seven individuals of *R. leschenaulti* (3 females and 4 males) and four of *C. sphinx* (2 females and 2 males) were selected and kept in two separate cages (80 × 50 × 50 cm). All the bats were adult and non-reproductive. Before the experiments were carried out, the bats were housed in the cages for 2 d with food (pieces of apple or banana) and water provided.

We gathered ripe *F. racemosa* and *F. hispida* fruits during their peak fruiting period (between 5 and 30 July 2005 for both species). Bats were fed after sunset each night and scats and ejecta were collected next morning over a period of 1 wk for both fig species. We offered fruits of *F. racemosa* to *R. leschenaulti* and *C. sphinx*, and *F. hispida* only to *R. leschenaulti*. The seeds then were collected and the germination patterns of three treatments were compared: (1) seeds from scats; (2) seeds from ejecta; (3) control seeds, which were obtained from ripe fruits taken directly from parent trees. The pulp was removed using a soft cloth and any pulp remains on the seeds were washed off. Sample sizes are shown in Table 1.

Seeds were placed in Petri dishes (10 cm in diameter) on moistened filter paper. Petri dishes were placed in an Intelligent Man-made Climatic Incubator (MGC-35HP-2, Yiheng Science and Technology Limited

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Table 1. Germination percentage (GP) of seeds from scats, ejecta and fleshy fruits. Percentages were compared with Kruskal–Wallis test.

Seeds	No. trials	GP Scats	GP Ejecta	GP Control	χ^2	P
Rousettus leschenaulti						
Ficus racemosa	6	98.4	99.7	99.8	1.55	0.461
F. hispida	6	99.2	95.6	99.5	3.10	0.212
Cynopterus sphinx						
F. racemosa	6	99.3	98.5	99.8	1.67	0.433

Table 2. Germination analysis of *Ficus racemosa* and *F. hispida* seeds using germination start (GS), minimum imbibition time (T_{min}) and time in which 50% of the seeds that compose GP (T_{50}) germinate.

		Rousettus leschenaulti		*Cynopterus sphinx*		
		Scats	Ejecta	Scats	Ejecta	Control
Ficus racemosa	GS(d)	4	4	4	4	4
	T_{min}(d)	3	3	3	3	3
	T_{50}(d)	5	5	4	4	4
Ficus hispida	GS(d)	6	6			5
	T_{min}(d)	5	5			4
	T_{50}(d)	6	7			6

Company, Shanghai, China), which maintained a constant temperature of 30 °C, and 12 h under light in a 24-h cycle. Petri dishes had been previously sterilized at 160 °C for 10 h, and treatments were moistened with distilled water periodically. We repeated each treatment six times, and each repetition consisted of placing at least 60 seeds in a Petri dish. The seeds in each of the Petri dishes were from different scats, ejecta and figs, but from the same nights. The numbers of seeds germinating was counted daily until there was no further germination for over 1 mo. Germinated seeds were removed as they were counted to reduce their effect on the remaining ungerminated seeds. Germination was defined as the emergence of any seedling part from the seed (Izhaki *et al.* 1995). Seed germination percentage was compared among treatments by means of the Kruskal–Wallis tests, as data could not be normalized with any transformation.

Quantitative evaluation of seed germination was based on the following four parameters: (1) final germination percentage (GP), which refers to the percentage of seeds capable of germinating under experimental conditions; (2) germination start (GS), which was defined as the time interval (d) between sowing and emergence of one-sixth of the final germination percentage of the seedlings (Izhaki *et al.* 1995); (3) minimum imbibition time (T_{min}), which is the minimum time required for the seeds to start germinating once they have absorbed the necessary amount of water; (4) time necessary for reaching 50% germination percentage (T_{50}), which indicates the time necessary for germination of half the seeds that germinated by the end of the experiment (Naranjo *et al.* 2003).

We found most seeds of *F. racemosa* germinated during the first 6 d for all the treatments and both bat species. For *F. racemosa*, manipulation by *Rousettus leschenaulti* did not significantly affect GP (Kruskal–Wallis test: $\chi^2 = 1.55$, $P = 0.461$). T_{min} and GS of the *F. racemosa* seeds ingested by *R. leschenaulti* (including seeds from scats and ejecta) were the same as those of control seeds. T_{50} was 4 d for control seeds but 5 d for seeds from scats and ejecta (Tables 1 and 2). The GP for *F. racemosa* seeds from *C. sphinx* scats and ejecta did not differ significantly from the controls (Kruskal–Wallis test: $\chi^2 = 1.67$, $P = 0.433$). The treatment received by *F. racemosa* seeds ingested by *C. sphinx* (including seeds from scats and ejecta) did not change T_{min} and GS. T_{50} was 4 d for all treatments (Tables 1 and 2).

Germination in *F. hispida* occurred within 1 wk and GP reached about 99% in all treatments after 7 d. The GP of *F. hispida* was not significantly affected by the manipulation by *R. leschenaulti* (Kruskal–Wallis test: $\chi^2 = 3.10$, $P = 0.212$) (Table 1). Compared with control seeds, the treatment received by the *F. hispida* seeds in the digestive tracts of *R. leschenaulti* resulted in an increase in T_{min} and GS of 1 d, which was also true for the seeds from ejecta. T_{50} was 6 d for control seeds and seed from scats, but 7 d seeds from ejecta (Table 2).

Our conclusion that GP of *F. racemosa* and *F. hispida* was not enhanced by passage through the digestive tracts of either bat species contradicts the observed improvement of seed germination of *Ficus* spp. after ingestion by pteropodid bats in the Philippines (Utzurrum 1995), and many other studies (Figueiredo & Perin 1995, Lieberman & Lieberman 1986, Shilton *et al.* 1999). However, Sosa (1997) found that ingestion of *Stenocereus thurberi* (Cactaceae) by bats did not affect germination, which was consistent with our results.

Seeds of *F. racemosa* from scats and ejecta of *R. leschenaulti* had a T_{50} 1 d longer than that of control seeds, but those from *C. sphinx* did not (Table 2). Differences in seed responses of the same species to ingestion by different frugivores, even when frugivores belong to the same family, as with our results, have been found in a variety of plants (Traveset 1998). Likewise, the effect produced by ingestion of seeds by the same bat species may vary according to the plant species. In our experiment, the GS and T_{min} of *F. racemosa* seeds from scats and ejecta of *R. leschenaulti* were not changed, but GS and T_{min} of *F. hispida* seeds from scats and ejecta of *R. leschenaulti* were 1 d later than control seeds (Table 2). Since the same dispersers are involved, the difference must be in the seeds or in the molecular structure of the inhibitor (Naranjo *et al.* 2003).

Cynopterus sphinx and *Rousettus leschenaulti* are wide-ranging frugivorous species (Tang *et al.* 2005), and are more likely to cover long distances and hence transport fruits/seeds further than smaller-sized frugivores with relatively restricted ranges, such as *Balionycteris maculata*

(Hodgkison *et al.* 2003b). Frugivorous bats have been reported to swallow as much as 80% of the tiny seeds of figs (Morrison 1980). Due to the short transit time through the digestive systems of bats, we suggest that ingestion has only a minor scarifying effect on the testa of the seeds. So lots of viable seeds were dispersed by bats through excretion. Because these two bat species often change their feeding roost and they frequently excrete during flight, the seeds from scats can be dispersed extensively. Observations of captured bats in cages producing defecations after the cages were cleaned in the morning indicated that they could potentially retain fig seeds in their digestive tracts for longer time periods and thus have the potential to disperse them over longer distances, as suggested by Shilton *et al.* (1999), who found seeds of *Ficus septica* and *F. variegata* can be retained in the digestive tract of *C. sphinx* for > 12 h and were still viable.

In summary, the seeds of two fig species that have passed through the digestive tract of both bat species germinate as well as the control seeds except that some parameters were changed. In order to identify the actual significance of change of seed germination behaviour in seedling establishment and figs regeneration, future work should be focus on seed fate once deposited and seedling establishment.

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