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Predation and dispersal of Parah tree (*Elateriospermum tapos*) seeds by red spiny rats (*Maxomys surifer*) in Khao Nan National Park, Thailand

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Abstract

Aim : Seed predation and dispersal by scatter-hoarding rodents are important for plant population dynamics and forest structure. In this study, the potential of red spiny rats (*Maxomys surifer*) as predators, dispersers and scatter-hoarders of Parah (*Elateriospermum tapos*) seeds was examined in Khao Nan National Park, Thailand.

Methodology : One thousand Parah seeds and 100 rats were used in this experiment. Ten seeds with one rat were set inside a cage. Infrared videos of seed predation and dispersal by the rats were made from 9:00-10:00 p.m. afterwards, the numbers of seeds predated (predated, undamaged, and partially predated), dispersed (non-removed, displaced and removed) and scatter-hoarded were recorded.

Results : The percentage of undamaged, predated and partially predated seeds, as well as of removed, non-removed, and displaced seeds differed significantly. In both males and females, most of the seeds were undamaged, followed by those predated and partially predated. Additionally, most of the seeds were not removed, followed by those removed and displaced. Both males (35%) and females (37%) scatter-hoarded seeds, and the seed numbers did not differ between sexes. Body weight of rats was positively correlated with the percentage of predated seeds and negatively correlated with the percentage of undamaged seeds, but not with the potentially viable, non-removed, displaced, or removed seeds.

Interpretation : Red spiny rats act as predators, dispersers and scatter-hoarders of Parah seeds. It indicates that these rats may play an important role in Parah population dynamics.

Introduction

In plant populations, seed predation is a central demographic process that occurs repeatedly during every plant reproductive cycle (Vander Wall *et al.*, 2005; Fedriani and Manzaneda, 2005). Seed predation by predators cause severe loss of seed crops (Kurkjian *et al.*, 2016), but it has been proved that seed predators act as keystone species in some habitats (Brown and Heske, 1990). Seed predators contribute to seed germination by manipulating seeds (e.g., removing pericarp and seed coats), which may enhance germination if the prepared seeds are only partially, and not fully predated, or are dispersed far away or buried (Perea *et al.*, 2011; Yang and Yi, 2012). Seed dispersal is another important factor for the life cycles of most plants, as dispersal process includes 'departure of a diaspore (e.g. seed or fruit) from the parent plant' (Howe and Smallwood, 1982) and it is necessary for plant regeneration (Traveset, 2014). The interplay between seed predation and dispersal is an important determinant of seedling establishment in forests.

Scatter-hoarding of seeds by frugivores is another important factor that is adequate for seed germination (Kitamura *et al.*, 2004). Scatter-hoarders store seeds for later consumption in several caches located spatially apart, but, in some cases, they forget the caches, and the forgotten seeds have high survival and establishment probabilities (Hulme, 2002; Jansen *et al.*, 2012). Therefore, seed caching influences seedling recruitment probabilities (Forget *et al.*, 2002; Hirsch *et al.*, 2012).

Seed predation and dispersal by scatter-hoarding rodents influence seed survival probabilities, and these processes are very important for the establishment and maintenance of many plant populations (Wenny, 2001; Jansen *et al.*, 2004). Though rodents consume a large amount of seeds but they contribute to direct dispersal by taking and depositing the seeds directly in suitable locations for establishment (Wenny, 2001), such as pine seeds cached by small rodents after wind dispersal in western North America were taken to sites more suitable for establishment than seeds dispersed by wind alone (Vander Wall, 1993). Rodents act as important seed predators and dispersers, that is why they have been used frequently as model organisms to investigate the effects of seed predation and dispersal on the dynamics of plant populations (Hulme, 2002; Jansen *et al.*, 2004; Galetti *et al.*, 2015).

Rats, especially *Maxomys* spp. (i.e., *Maxomys surifer*, *Maxomys whiteheadi*) are known as abundant and omnivorous forest dwellers in rainforests (Wells *et al.*, 2004), but very few researches have been conducted to investigate their roles as seed predators, dispersers, and/or scatter-hoarders (Blate *et al.*, 1998; Curran and Leighton, 2000; Kitamura *et al.*, 2004; Wells and Bagchi, 2005). In tropical forests in Thailand, the red spiny rat (*M. surifer*) is a dominant small mammal species (Walker and Rabinowitz, 1992), but only one study has reported it as a seed predator and scatter-hoarder of *Aglaia spectabilis* (Kitamura *et al.*, 2004). No study has been conducted to find out their potential

as seed predators, dispersers and scatter-hoarders of Parah trees (*Elateriospermum tapos*).

The Parah forest at Khao Nan National Park, southern Thailand, provides both direct and indirect non-timber benefits to the local communities. Most of the related products are harvested throughout the year for household consumption or subsistence income, but Parah seeds are only collected during the mast fruiting season from August to October (Charoensuk *et al.*, 2012). Normally, the harvesting of non-timber products has negative ecological effects on forests, especially on tree population size and population age structure (Brites and Morsello, 2012). In this case, some animal agents, especially rodents, are very important for plant recruitment, through dispersal and partial predation of seeds (Forget, 1993; Hulme, 1997). In view of the above, the present study was carried out with the following objectives : to determine the role of red spiny rats as seed predators, seed dispersers and/or scatter-hoarders of Parah seeds; to determine the differences in these roles between male and female red spiny rats and to examine the correlation between rat body size and percentage of predated and dispersed seeds.

Materials and Methods

Study site : Khao Nan National Park covers an area of 410 km², including a part of the Nakhon Si Thammarat mountain range from north to south. There are five main Parah clusters in Khao Nan National Park, covering 8.1 km². This study was conducted at the largest Parah cluster at Ban Tub Namtao with a total area of 4.1 km² (Fig. 1).

Parah biology : Parah (*Elateriospermum tapos*), belonging to the family Euphorbiaceae, is found in Southeast Asian tropical rainforests. This species is a dominant tree in Khao Nan National Park. Parah fruit, when ripe, is oblong-ellipsoid, with a yellowish endocarp and contains up to three seeds. Seed size is 3.2-3.6 cm in length and 1.4-2.2 cm in width. The experiment was conducted during Parah mast-fruiting season (August-September, 2015).

Rat trapping : Twenty locally made cage traps (20x20x40 cm³) baited with ten Parah seeds per cage were placed for 40 consecutive days on the Parah forest floor, comprising a total trapping effort of 800 trap nights. The cage traps were placed at 5:00 p.m. and the trapped rats (*Maxomys surifer*) were collected next morning between 6:00-7:00 am. The rats were brought back to the research facility and kept in the cage, without food, until the experiments were conducted. One hour before conducting the experiments, rats were weighed using a digital balance and their body size (i.e., foreleg length, hind leg length, and total body length) were measured with a measuring tape. In this study, 100 red spiny rats (51 males and 49 females) were captured for conducting the experiment.

Experimental design : One thousand Parah seeds, with no signs of predation or germination, were collected from beneath

Parah fruiting trees. Ten selected Parah seeds were set in a net cage ($1 \times 1 \times 0.70 \text{ m}^3$ with 2 cm mesh size) and one rat was released into the cage ($N = 100$, 51 males and 49 females). Due to rat nocturnal feeding behaviors, all feeding observations were conducted between 9:00-10:00 p.m. with a maximum of three trials per night, using three sets of cages and video cameras (Panasonic Lumix GF2) with an infrared light. After the trial was completed, the rats were left undisturbed and released at the place of capture next day. The number of seeds predated was noted at the end of each trial. A new set of seeds was placed in the cage prior to new trial.

In the present study, seed dispersal was classified as non-removed (seeds found at their original positions); displaced (seeds found less than 50 cm from their original positions) and removed (seeds found more than 50 cm from their original positions). Seed predation was classified as undamaged (no sign of predation); partially predated (more than half of the seed was in good condition) and predated (more than half of the seed was consumed). Rats that moved the seeds from the original seed positions and tried to hide them in the corner of the cage were defined as scatter-hoarders of Parah seeds.

Statistical analysis : Parametric statistics were used when underlying assumptions were met. Percentage data were

transformed by arcsine (in degree) transformation. The sexual differences in rat body size, weight and the numbers of scatter-hoarded seeds were examined using *t*-tests. Two-way ANOVA tests with post-hoc Bonferroni adjustment were used to test the effects of treatments, sex, and their interactions on seed predation, and dispersion, separately. Linear regression analyses between rat body weight and the number of seeds predated/dispersed were tested. All tests were two tailed and statistically significant at the level $P < 0.05$.

Results and Discussion

The body size and weight of *Maxomys surifer* did not differ between sexes (Table 1), and both sexes displayed scatter-hoarding behavior (35% males and 37% females). The average number of scatter-hoarded Parah seeds did not differ between the sexes (Table 1). In previous studies, it was observed that the body size or weight did not differ between sexes in jumping mouse (*Zapus hudsonius*) from Ohio, United States, hispid pocket mice (*Chaetodipus hispidus*) from Manhattan, Kansas, and in albino rats (*Rattus norvegicus*) from Zaria, Nigeria (Rybak *et al.*, 1975; Kaufman *et al.*, 2012; Aguh *et al.*, 2013). In some rodent species, when there was no difference in body size between males and females, individuals chose their mates by olfaction rather than by contests. In this case, a female was

Fig. 1 : Map of Khao Nan National Park, Southern Thailand. Black line represent Khao Nan National Park boundary, red star represents the park headquarters and red line represents the study area

Table 1 : Sexual differences in body size, body weight and scatter-hoarded seed numbers in red spiny rats (*Maxomys surifer*)

Measurements	Male	Female	Statistical test
Body size			
Standard body length (cm)	16.95 ± 0.54	17.89 ± 0.59	$t_{98} = -1.16$
Foreleg length (cm)	4.26 ± 0.16	4.41 ± 0.18	$t_{98} = -0.62$
Hind leg length (cm)	6.05 ± 0.18	6.40 ± 0.24	$t_{98} = -1.16$
Body weight (g)	209.12 ± 13.62	219.39 ± 15.57	$t_{98} = -0.49$
Number of scatter-hoarded seeds	3.78 ± 0.59	4.22 ± 0.73	$t_{34} = -0.46$

Values are mean of replicates ± SE

attracted by a male's odors, which transmitted several pieces of information regarding the male's dominance status and physical condition (discussed in Lu *et al.*, 2014).

Treatments had effects on seed predation, but sex, and the interaction between treatments*sex, did not have any effects (two-way ANOVA : treatment : $F_{2, 294} = 157.56$, $P < 0.001$, sex : $F_{1, 294} = 0.07$, ns, treatments*sex : $F_{2, 294} = 0.63$, ns). From Bonferroni's post-hoc tests, most of the seeds were undamaged followed by those predated and partially predated by rats ($P < 0.005$) (Fig. 2a). Treatments had effects on seed dispersal but sex, and the interaction between treatments*sex, did not have any effects (two-way ANOVA : treatment : $F_{2, 294} = 101.82$, $P < 0.001$, sex : $F_{1, 294} = 0.01$, ns, treatments*sex : $F_{2, 294} = 0.14$, ns). Bonferroni's post-hoc tests showed that most seeds were non-removed by rats, followed by those removed and displaced ($P < 0.005$) (Fig. 2b).

The results showed that both male and female *M. surifer* acted as seed predators, dispersers and scatter-hoarders of Parah seeds. Several studies have reported that many rodent species act as seed predators or dispersers in several parts of the world, such as spiny rats (*Proechimys semispinosus*) in neotropical forests in central Panama (Hoch and Adler, 1997); Malayan porcupines (*Hystrix brachyura*), red spiny rats (*M. surifer*), and variable squirrels (*Callosciurus finlaysonii*) in Thailand (Kitamura *et al.*, 2004), black agoutis (*Dasyprocta fuliginosa*) and green acouchis (*Myoprocta pratti*) in Brazil (Haugaasen *et al.*, 2010); Asiatic brush-tailed porcupines (*Atherurus macrourus*), Himalayan striped squirrels (*Tamiops macclellandi*), hoary-bellied squirrels (*Callosciurus pygerythrus*), Pallas red-bellied squirrels (*Callosciurus erythraeus*) and Malayan giant squirrels (*Ratufa bicolor*) in India (Sidhu and Datta, 2015); and Korean field mice (*Apodemus peninsulae*), Siberian chipmunks (*Tamias sibiricus*), gray red-backed voles (*Clethrionomys rufocanus*), and Edward's

Fig. 2 : Seed predation and dispersal by red spiny rats (*Maxomys surifer*); (a) mean percentage of seed predation and (b) mean percentage of seed dispersal. Different alphabet letters indicate significant differences among treatments and between sexes. Gray and white bars indicate male and female rats, respectively. Bars represent mean values ± SE

Fig. 3 : Red spiny rat (*Maxomys surifer*) body weight (g), seed predation and seed dispersal; (A) predated seeds, (B) undamaged seeds, (C) partially predated seeds, (D) non-removed seeds, (E) displaced seeds and (F) removed seeds

long-tailed rats (*Leopoldamys edwardsi*) in China and India (Yi *et al.*, 2015; Sidhu and Datta, 2015).

Some species of rodents are important for scatter-hoarding of seeds, such as Korean field mice (*A. peninsulae*),

Siberian chipmunks (*T. sibiricus*), gray red-backed voles (*C. rufocanus*), and red spiny rats (*M. surifer*) in China and Thailand (Yi *et al.*, 2015; Kitamura *et al.*, 2004). The scatter-hoarding of seeds involves transportation of seeds away from the parental trees, which is required for the colonization of new sites

(Stapanian and Smith, 1978). Burial protects seeds from seed predation, as well as from the effects of extreme temperature and UV radiation (Roth and Vander Wall, 2005) and places the seeds in a favourable environment for seed germination. Because of these reasons, the scatter-hoarding of seeds by rats is crucial for the successful recruitment of seeds.

It was observed that more than 10% of Parah seeds were partially predated by male and female rats. Normally, partially consumed seeds germinate more rapidly, and with a higher rate of success, than intact seeds (Pérez et al., 2008; Perea et al., 2011; Yang and Yi, 2012), though we did not test the seed germination rate of partially predated Parah seeds. Probably, the germination process is accelerated when seeds are damaged, as this process has been attributed to some physiological responses, due to removal of seed coat or other barriers to imbibition (Pérez et al., 2008). Therefore, the partial predation of seeds allows faster penetration of water into the seed (Finch-Savage and Clay, 1994).

Seedling establishment is also significantly affected by heavy partial consumption by rodents (Perea et al., 2011). A few studies have observed that partially consumed acorns (*Quercus* spp.) germinate more rapidly than intact ones (Perea et al., 2011; Yang and Yi, 2012). Moreover, Wada and Kamata (2003) observed that seedlings developed from partially cotyledon-removed acorns showed a higher relative growth rate than those from intact ones (Wada and Kamata, 2003). So, the tolerance of seeds to partial consumption is an important reproductive strategy, which enables the recruitment of trees (Perea et al., 2011).

The percentage of predated seeds (PS) was positively correlated with male and female rat body weight (RBW) (male: $R^2 = 0.19$, $F_{1,49} = 11.43$, $Y_{PS} = 0.05X_{RBW} + 15.64$, $P < 0.005$; female: $R^2 = 0.41$, $F_{1,47} = 31.99$, $Y_{PS} = 0.08X_{RBW} + 9.70$, $P < 0.001$, Fig. 3a). On the other hand, the percentage of undamaged seeds (US) was negatively correlated with male and female rat body weight (male: $R^2 = 0.09$, $F_{1,49} = 4.82$, $Y_{US} = 64.84 - 0.04X_{RBW}$, $P < 0.05$; female: $R^2 = 0.20$, $F_{1,47} = 11.93$, $Y_{US} = 69.49 - 0.08X_{RBW}$, $P < 0.005$, Fig. 3b). There was no association between the percentage of partially predated seeds and rat body weight (male: $R^2 = 0.000$, $F_{1,49} = 0.02$, ns; female: $R^2 = 0.00$, $F_{1,47} = 0.009$, ns, Fig. 3c). The percentage of non-removed, displaced, and removed seeds were not associated with rat body weight (non-removed seeds-male: $R^2 = 0.07$, $F_{1,49} = 3.7$, ns; female: $R^2 = 0.02$, $F_{1,47} = 1.17$, ns; displaced seeds-male: $R^2 = 0.01$, $F_{1,49} = 0.23$, ns; female: $R^2 = 0.01$, $F_{1,47} = 0.39$, ns; removed seeds-male: $R^2 = 0.08$, $F_{1,49} = 4.35$, ns; female: $R^2 = 0.02$, $F_{1,47} = 1.10$, ns, Fig. 3d-f).

It was observed that rat body weight was positively correlated with the percentage of seeds predated and negatively correlated with the percentage of undamaged seeds. This indicates that the ability of rats to prey upon seeds is related to rodent body mass; therefore, heavier the rodent, greater the capacity to prey on a higher percentage of seeds. There was no

relation between rat body size and seed dispersal. Until now, very few researches have reported the relationships between rodent body mass and seed predation/dispersal in order to observe the effects of body mass on seed consumption/dispersal (Galetti et al., 2015). Normally, animal body size and weight affects seed predation. Galetti et al. (2015) observed that the probability of seeds being preyed upon increased sharply with an increase of the body mass of seed predators (rodents: *Euryoryzomys russatus*, *Sooretamys angouya*, *Nectomys squamipes*, and *Trinomys iheringi*). They found that, on average, individual rodents with ≤ 65 g of body mass consumed not more than 5% of the offered seed species, while rodents with 95 g of body mass preyed upon 20% of the seed species offered, and rodents with a body mass of over 165 g preyed upon over 90% of the offered seed species. Not only body weight, but also body size, influences the seed predation of animals. Birds with broader gapes consume higher numbers of fruits than birds with narrow gapes and larger sized gastropods swallow more seeds and consume more fruit skin area than smaller sized gastropods, respectively (Wheelwright, 1985; Türke and Weisser, 2013).

The present study shows that red spiny rats (*M. surifer*) act not only as seed predators and dispersers, but also as scatter-hoarders of Parah seeds and that larger rats predate more seeds than smaller ones. It is well known that predation, dispersal and scatter-hoarding of seeds by rats are very important to determine the seedling establishment and regeneration of plants in forests. Thus, the results of this study can be interesting for the conservation of this valuable rat species in Khao Nan National Park, Nakhon Si Thammarat, Thailand, for the proper management of the Parah forest. However, in order to have a better conservational policy, further studies should be conducted to determine the potential of *M. surifer* of being seed predators, dispersers and scatter-hoarders of other tree species in Thailand.

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