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THE IMPACT OF GUT PASSAGE BY BINTURONGS (*ARCTICTIS BINTURONG*) ON SEED GERMINATION

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ABSTRACT. — Binturongs (*Arctictis binturong*) are the largest of Asian civets and, due to their highly frugivorous diet, are expected to play an important role in seed dispersal processes. To study the effect of binturong gut passage on seed viability, we fed 10 captive binturongs with fruits of longan (*Dimocarpus longan*), papaya (*Carica papaya*) and chiku (*Manilkara zapota*), collected the seeds they defaecated, and planted these to determine seed germination rate and time. Of the defaecated seeds, 90.4% passed through binturong gut intact in under nine hours, and 99.4% passed in under 33 hours. Chiku seeds had the highest germination rate (35.7% and 34.8% for ingested and control seeds, respectively), followed by papaya (30.8% and 27.6%) and longan (18.9% and 29.8%). The germination rate of longan seeds ingested by binturong was significantly lower than that control seeds, while for the other two species there were no differences. All three species germinated approximately three days faster after gut passage, which may increase seedling survival. This study indicates that binturongs may be effective agents of seed dispersal for some fruit species.

KEY WORDS. — carnivore, ecological function, endozoochory, germination, seed dispersal, seed viability

INTRODUCTION

The role of tropical rainforest carnivores in seed dispersal is poorly known, yet merits further investigation given their potential significance in forest maintenance and regeneration. In light-deprived tropical rainforests, plants may gain a competitive advantage by increasing seed size but large seed size also limits the range of potential animal dispersers (Corlett, 1998; Jordano, 2000). Binturongs (*Arctictis binturong*) are the largest civet species (Jennings & Veron, 2009), as well as one of the most frugivorous (McKenny, 2011; Rozhnov, 1994) and widespread, making their potential role in tropical forest seed dispersal significant, even in light of recent population declines (Widmann et al., 2008).

In spite of their potential importance, few studies have addressed the role of binturongs in seed dispersal. Shannahan (2000) found that fig (*Ficus* sp.) seeds fed to captive binturongs had a passage time of three hours and germinated afterwards. More is known for other Asian civets. For example, brown palm civets (*Paradoxurus jerdoni*) in India's Western Ghats were found to be predominantly frugivorous: fruits made 97% of their diet and they consumed fruits of 57

plant species (Mudappa et al., 2010). Jothish (2011) noted that papaya (*Carica papaya*) comprised the majority of fruit in common palm civet (*Paradoxurus hermaphrodites*) diet in Kerala, India, and germinated readily after passing by the civet's gut. Other studies on common palm civet revealed high viability of seeds germinated from scat (Joshi et al., 1995), and higher seedling survival of rambutan (*Nephelium lappaceum*) defaecated by civets compared to seeds spat out by macaques (Nakashima et al., 2010).

The effect of vertebrate gut passage on seed germinability is mediated by several factors, such as seed retention time or differences among seed types and plant species (e.g., Traveset, 1988). Traveset (1998) found that seed dispersal agents impact the germinability and/or the rate of germination of seeds in approximately half of the woody plants consumed, and enhance germination in temperate zones more frequently than in the tropics, perhaps because of being more advantageous in unpredictable environments. Indeed, several temperate small carnivores have been observed to increase germination success as a result of endozoochory. Passage through the gut of two fox species improved germination rates for several species of native plants in

the Chaco (Varela & Bucher, 2006) and of Mediterranean hackberry (Juan et al., 2006). *Vaccinium* and *Rubus* seeds also showed germination enhancement after gut passage through martens (*Martes foina*, *M. martes*; Schaumann & Heinken, 2002) and American martens (*Martes americana*; Hickey et al., 1999). Among Old World carnivores, small-toothed ferret badgers (*Melogale moschata*) were found to be valid if inefficient seed dispersers (Zhou et al., 2008). Although no germination trials were conducted, a study of the effect of gut passage through common palm civets on coffee beans revealed surface micro-pitting and breakdown of storage proteins from digestive juices (Marcone, 2004).

Listed by the IUCN as Vulnerable (Widmann et al., 2008), the binturong is the largest member of the Viverridae, weighing approximately 9–20 kg (Jennings & Veron, 2009). Despite their size, binturongs are highly arboreal and one of the few tropical Old World mammal species with a prehensile tail (Jennings & Veron, 2009). Binturongs move slowly and deliberately through trees, but also make frequent descents to the ground, which increases their vulnerability to hunting (Jennings & Veron 2009). Ranging throughout the tropical regions of India, Nepal, Bhutan, Bangladesh, Burma, China, Thailand, Laos, Malaysia, Indonesia, and the Phillipines (Wozencraft, 2005), binturongs have been observed in open forests and grasslands (Esselstyn et al., 2004), but prefer closed canopy forests, perhaps because of their high level of fruit production (Jordano, 2000).

Binturongs exhibit little territorial behaviour, with 35% home-range overlap (Grassman et al., 2005). A study of five adult binturongs in Thailand showed arrhythmic and crepuscular activity levels, with mean home ranges of 6.2 km² with daily movement averaging 688 m (\pm 677 m) and daily activity levels of 47%. Home range and activity levels depended on seasonal fruit availability (Grassman et al., 2005). Activity levels for captive individuals also ranged from 18.2 to 33.3% depending on the season (Rozhnov, 1994). Formerly presumed to be nocturnal, there are increasing reports of diurnal sightings (Jennings & Veron, 2009).

Defined as a hypocarnivore (Shrestha et al., 2011) binturongs preferentially consume high carbohydrate fruit, and digest it several orders of magnitude faster than similar sized primates (McKenny, 2011). This allows them to minimally process large quantities of fruit remarkably quickly. Despite this high degree of frugivory, binturongs have an unusually short gut and lack a cecum (McKenny, 2011), and do not exhibit carbohydrate fermentation typical of frugivores (Lambert et al., 2010). These characteristics result in unusually low dietary efficiency (Dierenfeld, 2003) and lead to the production of high quantities of minimally digested food in their scat (C. Colon, pers. obs.). Their dental morphology, with large canines and pronounced carnassials, may also reduce the extent to which they masticate food, which would likely further reduce potential negative impacts of gut passage (McKenny, 2011).

The goal of this study was to examine the effect of gut passage on seed germination for three plants whose fruits were fed

to Southeast Asia's largest predominantly frugivorous palm civet, the binturong. Because binturongs retain an ancestral morphology for carnivory and are ill suited for digestion of fruit, it was presumed that they would process large quantities of fruit in a short time, and that all fruit would be swallowed whole and defaecated quickly. It was therefore hypothesized that passage through binturong gut would either have no impact or some positive impact on seed viability and germination of the three target plant species.

MATERIAL AND METHODS

To test the effect of gut passage on seed viability, we compared the germination of seeds consumed by binturongs and control seeds directly obtained from the fruit (i.e., not consumed). We selected longan (*Dimocarpus longan*), papaya, and chiku (*Manilkara zapota*) due to the palatability of their fruits to binturongs and their common occurrence in the region, either as cultivars (longan, papaya, and chiku; Chong et al., 2009) or native forest species (longan; Corner, 1997). Papaya seeds at 6.3 mm in length were the smallest seeds used in the study; chiku seeds were the longest, with an average maximum length of 23 mm; and the spherical longan seeds were the largest, averaging 14.3 mm diameter. Chiku and papaya fruits were cut into 5 cm cubes while longan fruit average 2.9 cm in diameter and were offered whole.

We conducted the feeding trials on 10 healthy adult captive binturongs at the Singapore Zoo Night Safari, during Jan. and Feb. 2011. The binturongs (6 males and 4 females) ranged from 6–18 years in age. Enclosures ranged in size from under 3 m² shift cages to over 10 m². Overall activity levels were not monitored but most animals were inactive for most of the day.

For the feeding trials, most binturongs were maintained in separate enclosures that allowed individual feeding and identification of scats. For individuals housed together at night, dragon-fruit or kiwi were used as markers to identify scat from specific individuals. Their prepared diet consisted of bananas, apples, papaya, orange, melon, and eggs supplemented with meat once per week. During the study, each animal was offered a minimum of 20 seeds

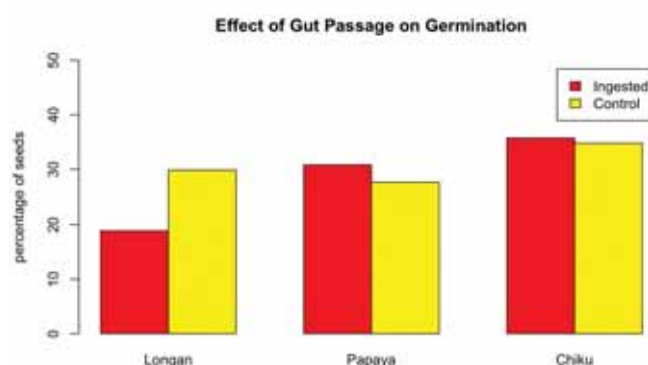


Fig. 1. Germination rate of longan, papaya, and chiku seeds ingested by binturongs (red) and non-ingested controls (yellow). Sample sizes, from left to right, are 742, 191, 799, 181, 28, and 23 seeds.

inside fruit of either longan, papaya or chiku on alternating days to track seed retention time. These fruits were offered in the food bowl along with all other diet items. In order to accommodate the feeding trials within the Night Safari routines, experimental seeds were generally fed at 0000 hours and scats were collected between 0900 and 1000 hours the following day. Initial observation of consumption indicated that fruits were hulled with the incisors then swallowed whole, with little to no mastication. For each scat, all intact seeds were removed and a sub-sample of up to 10 was randomly selected for germination. Any remaining spat seeds in the exhibit were recorded and discarded. Due to rodents, insects, slopes, moats and drains, accurate counts of seeds and fruit not eaten were not possible. Only seeds that were found in scat were germinated as experimental units.

Seeds retrieved from binturong scats and control seeds (not ingested by binturongs) were set to germinate to test the effect of binturong gut passage upon seed germination. The germination experiment was run at the nursery of Singapore's Botanic Garden in outdoor raised planting beds. All seeds were planted either the day they were extracted (from scat or fruit) or the day after. Seeds were maintained in plastic bags at room temperature before germination. Seeds were planted individually in seedling bags filled with standard potting mix, containing (in order of concentration) white sphagnum peat, black sphagnum peat, perlite, coarse sand, chipped pine bark, compost, and neem meal. Seeds were covered with 2 cm of soil and saturated with water. Seedling bags were randomly assigned a number and corresponding location on the beds. Seedlings were covered with chicken wire to prevent predation and watered daily. Average daily temperature was 26.5°C. Seedling bags were checked for signs of germination (emergence of an identifiable shoot above the soil) every 3 days until no signs of germination were seen for at least two weeks.

All statistical tests were conducted using the statistical environment R (R Core Team 2011, version R 2.13.2 for Mac). To test the effect of gut passage on both germination rate and germination time, we used generalized linear mixed models (GLMMs), in which the individual binturong was included as random variable and seed treatment (ingested

by binturong vs control), plant species (longan, papaya, or chiku), the interaction between seed treatment and fruit species (treatment*species), binturong sex (male vs. female), and age (in years) were included as fixed variables. The models of germination rate were fit using a binomial distribution of the error, and models of germination time using a poisson distribution. In all cases, significance was tested by means of likelihood ratio tests (LRTs) of the full model against reduced models.

RESULTS

Of the 6,163 seeds fed to binturongs, we recovered a total of 1,889 seeds that had been defaecated. Of these, the first 10 seeds from each defaecation were selected for planting, which included 742 longan, 799 papaya, and 28 chiku seeds. On one occasion a single longan seed that had been spat out showed signs of damage from teeth, otherwise there was no effort to sort seeds according to how they were orally processed, since it was not possible to observe each animal consume the fruit. Most seeds (90.42%, $N = 1,708$) were recovered the morning after being fed, (i.e., less than 9 hours after consumption). All chiku seeds were recovered at this time. Ninety longan (4.76%) and 79 papaya (4.18%) seeds were recovered 33 hours after seed ingestion. Only nine longan and three papaya seeds were recovered on the third morning (57 hours after ingestion).

We planted 1,964 seeds (1,569 ingested by binturong and 395 control), of which 511 (396 ingested and 115 control) germinated (Table 1). The germination rate of ingested seeds was 18.9% ($N = 140$) for longan, 30.8% ($N = 245$) for papaya, and 35.7% ($N = 12$) for chiku; and in the case of control seeds it was 29.9% ($N = 57$) for longan, 27.6% ($N = 51$) for papaya, and 34.8% ($N = 9$) for chiku. There was a significant interaction between seed treatment (ingested vs. control) and plant species ($\chi^2_2 = 10.654$, $p = 0.005$), indicating that the effect of gut passage through binturongs on germination was different across species. Binturong's age ($\chi^2_1 = 0.503$, $p = 0.478$) and sex ($\chi^2_1 = 1.342$, $p = 0.247$) had no significant effect on seed germination. When analysed by species separately, longan seeds consumed by binturongs

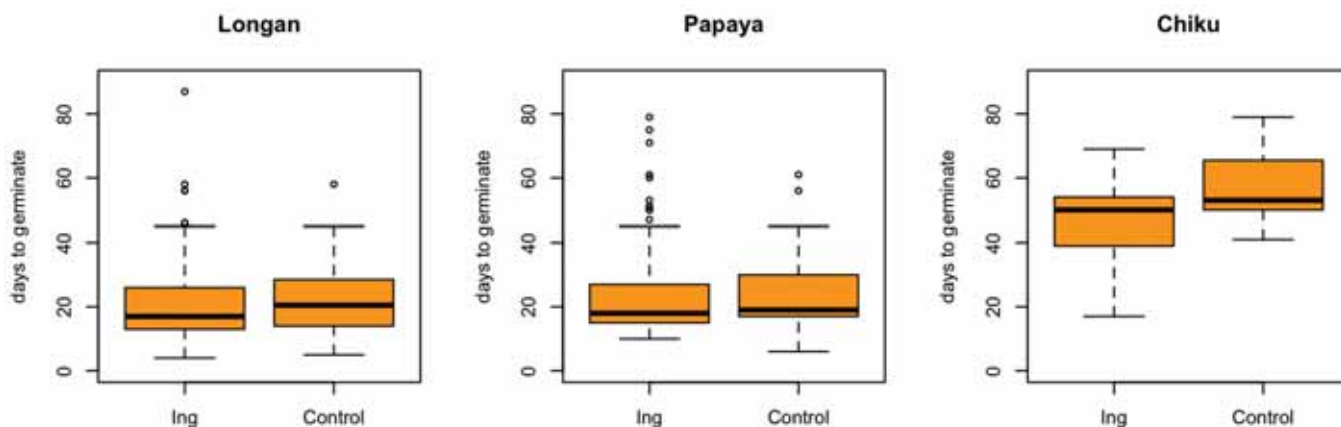


Fig. 2. Germination time of papaya, longan, and chiku seeds ingested by binturongs and non-ingested controls. Sample sizes, from left to right, are 799, 181, 742, 191, 28, and 23 seeds.

showed a lower germination rate than control seeds ($\chi^2_1 = 12.018$, $p < 0.001$), while papaya ($\chi^2_1 = 0.980$, $p = 0.322$) and chiku ($\chi^2_1 = 0.0006$, $p = 0.980$) showed no difference between ingested and control seeds (Fig. 1).

For the 511 seeds that germinated, the mean germination time was 23.1 days (range = 4–87 days). Mean germination time was shorter for ingested seeds than control seeds ($\chi^2_1 = 16.438$, $p = 5.03e^{-5}$) and also differed significantly among plant species ($\chi^2_2 = 427.9$, $p < 2.2e^{-16}$). Chiku had longer germination times (mean \pm SD = 46.3 \pm 14.4 days for ingested and 57.1 \pm 13.5 for control) than longan (20.4 \pm 11.8 days for ingested and 22.2 \pm 10.7 for control) and papaya (22.5 \pm 11.7 days for ingested and 23.7 \pm 11.6 for control). In this case, there was no interaction between seed treatment and plant species ($\chi^2_2 = 3.962$, $p = 0.138$; Fig. 2).

DISCUSSION

That gut passage had no significant impact on papaya or chiku seed viability, supported the research hypothesis of binturong gut passage having none or positive effect on germination and was consistent with Jothish's (2011) observation of high viability of papaya seeds in common palm civet scat. Shanahan et al. (2001) finding that figs (*Ficus annulata*) germinated readily after gut passage through binturongs further indicates that gut passage is benign.

The decreased viability of longan seeds after gut passage did not support our expectations. This decline may have resulted from undetected tooth activity during manipulation in the mouth while de-hulling, or separating the seeds from the flesh. It is also possible that gut action or digestive enzymes impacted the seeds. Chemical analyses and examination under a scanning electron microscope could detect evidence of mechanical or chemical breakdown as was observed on coffee beans defaecated by common palm civets (Marcone, 2004). Overall, it is not unusual that ingestion and gut passage by mammal frugivores has different effects on the germination of different plant species (e.g., Campos-Arceiz et al., 2012).

Because defaecated seeds germinated several days faster, they may have a competitive advantage over control seeds by reduced likelihood of predation. Seeds consumed by binturongs in the wild would also be transported away from the parent tree, thus reducing competition (Jordano, 2000). Based on gut passage time, activity levels and daily distance travelled, potential dispersal distance could range up to 600 m. Even seeds removed from the flesh and dropped on site may be at an advantage by virtue of removal of the hull and fruit pulp (Samuels & Levy, 2005). It is possible that any reduction in overall viability of unconsumed seeds may be offset by virtue of potential dispersal and removal of the hull and flesh through the foraging activity of binturongs. Unlike volant seed dispersers such as birds and bats, binturongs will descend to the ground when travelling through the forest, making terrestrial seed deposition more likely. In addition, informal observations indicate that binturongs in comparison

to primate frugivores are less likely to masticate seeds during processing, and therefore may have a lower physical impact on defaecated and dropped seeds. Finally, since binturongs are less diurnal than primates, their foraging activity may represent something of a night shift, during which they might harvest ripe fruit that would otherwise go uneaten by diurnal frugivores.

In this study, binturongs demonstrated their ability to swallow whole seeds of varying size and shape and defaecate them intact and viable. While the extent of its potential role as a seed dispersal agent remains unclear, this study provides a starting point for additional research. Further studies should include more feeding trials with different species of fruit and should entail greater resolution of gut passage rates, fruit processing and seed handling. While challenging, significant gaps in knowledge of forest regeneration could be filled through field studies of binturong feeding activity, scat deposition and seed germination patterns.

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