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Short communication

Seed removal by lizards and effect of gut passage on germination in a columnar cactus of the Caatinga, a tropical dry forest in Brazil

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ABSTRACT

The seed disperser's effectiveness relates to the qualitative and quantitative components of seed dispersal processes in terms of frequency, dispersal distance and seed germination. This study recorded *Tropidurus semitaeniatus* lizards acting as primary seed dispersers of *Pilosocereus gounellei*, a columnar cactus for which fruit morphology suggests ornitochory is its primary seed dispersal mode. We evaluated the effectiveness of seed dispersal by this lizard by experimentally assessing their qualitative and quantitative components. In 54 h of focal observations, lizards made 44 visits during different day time, with a mean dispersal distance of 6.50 ± 3.0 m. We collected (n = 96) intact and viable consumed seeds from 9 faecal samples. We conducted germination experiments with these seeds and compared the results to two other treatments: washed seeds and control. Passage through the lizard digestive tract positively affected the germinability, mean germination time, emergence rate index and synchronization index of *P. gounellei* seed germination when compared with the control treatment ($p < 0.05$). The results indicated that *T. semitaeniatus* is an effective seed disperser of *P. gounellei*, as the funicular pulp of this species produces allelopathic substances that inhibit seed germination. Consequently, this lizard's participation as a dispersal agent is necessary to ensure the successful germination of the cactus.

1. Introduction

Endozoochory is a seed dispersal mode that consist in the fruit consumption followed by liberation of viable seeds in faecal samples of dispersers (Fenner and Thompson, 2005). This plant-animal mutualism is a key ecological process to plant reproductive success and its effectiveness is assessed by quantitative and qualitative components (Schupp et al., 2010; González-Castro et al., 2015). The quantitative component is related to the abundance of disperser, frequency of visits, number of seeds dispersed and dispersal distance. The qualitative component refers to percentage and the germination speed of seeds after passage through the digestive tract and seed deposition site (Schupp et al., 2010; González-Castro et al., 2015).

In tropical forest, animal-mediated seed dispersal is the main strategy from 50% to 90% plant species (Howe and Smalwood, 1982). In these forests, many plants produce fleshy fruits adapted to animal consumption, while in dry environments with marked seasonality prevails anemochoric species or those dispersed by others abiotic factors (Gentry, 1982; Howe and Smalwood, 1982; Machado et al., 1997; Griz and Machado, 2001; Galetti et al., 2011; Jara-Guerrero et al., 2011; Freitas et al., 2013).

One of the families exhibiting endozoochorous dispersal in the Brazilian semiarid is Cactaceae, being one of the top four species-rich plant families in the ecosystem (Rodal and Sampaio, 2002). It is widely distributed in Caatinga (Taylor and Zappi, 2004). In arid and semiarid ecosystems, the cactus family provides different resources to pollinators and dispersers (pollen, nectar and fruits) (Taylor and Zappi, 2004). Its fleshy fruits contain succulent funicular pulp and a great diversity of shapes, scents and colours that attract distinct frugivores; such animals potentially act as effective seed dispersers (Taylor and Zappi, 2004). In this family, studies have

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shown seed dispersal by birds and bats as main primary dispersal modes in columnar cacti (Soriano et al., 1999; Ruíz et al., 2000; Godínez-Álvarez et al., 2002; Rengifo et al., 2007; Gomes et al., 2014), and lizards as dispersers more common in globose cacti (see review in Gomes et al., 2013).

Saurochory is an ecological process in which lizards mediate seed dispersal (Valido and Olesen, 2007). Lizards typically detect fruits using color, scent, proximity to the ground or location on the ground for fallen fruits (Van der Pijl, 1982). Seed dispersal by lizards has been reported by the family Cactaceae, nonetheless all records are restricted to the genus *Melocactus* Link & Otto, whose species present growth near to the ground, conical-shaped and colourful fruits, characteristics that facilitate the detection and consumption of fruits by different lizard's species (Vasconcellos-Neto et al., 2000; Taylor and Zappi, 2004; Gomes et al., 2013).

We observed *Tropidurus semitaeniatus* Spix 1825 (Squamata, Tropiduridae) climbing upon and taking seeds from fruit on the branches of *Pilosocereus gounellei* (F.A.C. Weber) Byles & Rowley subsp. *gounellei* (hereafter *P. gounellei*) in the Caatinga, a Brazilian semiarid ecosystem. *Pilosocereus gounellei* is a columnar cactus that grows up to 4 m in height, and its fruit morphology (e.g. large size, colourful, succulent pericarp) suggests ornitochory as a primary means of seed dispersal, similar to other *Pilosocereus* and columnar cacti species (Silvius, 1995; Soriano et al., 1999; Godínez-Álvarez et al., 2002; Rengifo et al., 2007; Gomes et al., 2014). This first involves a process of endozoochory, which involves mammals or birds followed by a secondary dispersal by invertebrates, such as ants (Traveset et al., 2014). However, Munguía-Rosas et al. (2009) in Mexico reported the removal of seeds by ants in *Pilosocereus leucocephalus* (Poselg.) Byles & G. D. Rowley, and emphasized the role of this group of animals as primary dispersers in addition to birds.

While focally observing the primary consumption of *P. gounellei* fruits by birds (Gomes, unpublished data), we also observed *T. semitaeniatus* lizards acting as primary seed dispersers of this columnar cactus. We experimentally evaluated the lizards' effectiveness as dispersal agents by determining the effect of passage through its digestive tract regarding the germination of seeds (qualitative component) as well as their visit frequency (quantitative component).

2. Materials and methods

We carried fieldwork in the reserve RPPN Fazenda Almas, located within the municipalities of Sumé and São José dos Cordeiros (7°28′15″ S and 36°52′51″ W), State of Paraíba, in the semiarid region of northeastern Brazil. The RPPN has 3505 ha of preserved area and is located in the region with the lowest rainfall record for the Caatinga. The climate of the region is characterized by extreme conditions, high radiation, low relative humidity and cloudiness. The average annual rainfall varies from 500 to 800 mm and high average annual temperature varies from 26 to 33 °C (Prado, 2003).

We carried out focal studies on one population of *P. gounellei* on rocky outcrops. This species is a columnar cactus commonly known as “xique-xique”, occurs exclusively in Brazilian semiarid and is widely distributed in the Caatinga vegetation. *Pilosocereus gounellei* has stem covered with spines, white tubular flowers with nocturnal anthesis, and dehiscent fleshy fruits with great number of small black seeds embedded in an intense pink funicular pulp (Zappi, 1994) (Fig. 1). *Tropidurus semitaeniatus* is an endemic lizard species to the Caatinga and broadly distributed in rocky habitats (Passos et al., 2011). It is a medium-size lizard (maximum snout–vent length = 72.4 mm), classified as carnivorous and/or omnivorous, with a generalized diet including invertebrates, leaves, fruits and seeds (Cooper and Vitt, 2002).

We performed focal observations on five individuals of *P. gounellei* over six non-consecutive days during the fruiting peak in February/2012. Each session of focal observations lasted 1 h, interpolated with 20 min intervals between focal observations, adding up to a total of 54 h of focal observation. We recorded the frequency of visits and behavior of lizards from 6 a.m. to 6 p.m.

We also investigated the effect of seeds' passage through the digestive tracts of lizards. That germination experiment was composed of three treatments: germination of seeds consumed by lizards (consumed seeds), germination of seeds manually washed in the laboratory for the removal of funicular pulp (washed seeds) and seeds that were not washed or consumed (control). We obtained the washed and control seeds (n = 100 per treatment) randomly from fruits of five different plants. To obtain dispersed (consumed) seeds, we collected fecal samples of different lizard individuals (n = 14 scats; totaling 96 seeds) at different distances from the reproductive adult cactus.

All collected seeds were counted and analyzed using stereomicroscope and then were submitted to germination tests under optimal conditions (30 °C, photoperiod 12 h) following Meiado (2012). We repeated each treatment four times, using seeds placed on a Petri dish, covered with two layers of filter paper moistened with distilled water. The dishes were sealed with transparent masking tape and, we did not recorded contamination by fungi. We counted the germinated seeds and removed them from the Petri dish each day during 30 days. In our experiment, germination was defined as the time when the radicle tip emerged $\geq$1 mm from the seed coat (Meiado, 2012).

At the end of the experiments, germinability (%), mean germination time [$t = \sum ni \cdot ti / \sum ni$, in which *ti* is the time since the onset of the experiment to the *n*th observation (days) and *ni* is the number of seed germinated in time *i* (not the accumulated number, but the number corresponding to the *n*th observation)], the emergence rate index adapted from Maguire (1962) [$GVI = (G_1/N_1) + (G_2/N_2) + \ldots + (G_n/N_n)$, in which G_1, G_2 and G_n correspond to the number of seeds germinated at the first, second and last count, respectively, and N_1, N_2 and N_n represent the number of days elapsed to the first, second and last count, respectively] and the synchronization index [$E = -\sum fi \cdot \log_2 fi$, in which *fi* is the relative germination frequency (i.e., the proportion of seeds germinated in a time interval)], were calculated based on Ranal and Santana (2006).

Differences in germination parameters among treatments (seeds consumed by lizards, washed seeds and control) were tested for statistical significance using a one-way ANOVA followed by a Tukey's honestly significant difference test. Data were expressed as mean standard deviation (SD) values. We tested the normal distribution of the data and homogeneity of the variances using Shapiro–Wilk and Levene tests, respectively. All statistical analyses were made with the STATISTICA 10.0, with a significance index of 0.05 (StatSoft, 2012).

3. Results and discussion

During the fruiting peak in February/2012, we counted 16 ripe fruits of *P. gounellei* available for consumption by frugivores species in the area. In 54 h of focal observation, we recorded 162 direct visits to fruits (Gomes, unpublished data). Seven species of birds (n = 118 visits) and the lizard *T. semitaeniatus* (n = 44 visits) carried out these visits. The lizards were responsible for 27% of the total number of visits, which corresponds to a frequency of 0.8 visit h^{-1} distributed in different times of the day. In this case, there was a higher concentration of visits during the morning (between 10 a.m. and 11 a.m.; n = 28 visits, 63% of the total).

The visits were about 30 s long as lizards climbed from branches of herbs surrounding the cacti to take seeds from *P. gounellei* fruits.