SHORT COMMUNICATION

Pollen consumption by free-living mice

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Abstract We present the first evidence of mice actively searching and consuming the pollen of Bromeliaceae and describe this behavior for the first time based on video-recorded evidence in the wild. Following repeated observations of nocturnal florivory in several individuals of *Tillandsia macropetala*, mice of the genus *Peromyscus* were recorded consuming pollen from this bromeliad during the dry season in the tropical montane cloud forest of central Veracruz, Mexico. The mice first consumed the anthers and, although it also consumed part of the filaments, the majority of these were discarded once the mice had consumed the pollen. The mice seem to be opportunistic consumers of pollen in a season when other resources are possibly scarce. It would be of value to determine the proportion of the rodent diet represented by pollen and other floral products during periods of low food availability, as well as to determine the potential impact of such herbivory on plant reproductive success.

Keywords Cloud forest · *Peromyscus* · Pollinivory · Rodentia · *Tillandsia* · Veracruz

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Introduction

Pollen constitutes an important dietary component for a wide variety of animals (Kearns and Inouye 1993), such as arthropods (e.g., Coleoptera, Hymenoptera, Lepidoptera, Collembola, Tettigoniidae, Thysanoptera, Diptera, and Decapoda) (Fischer et al. 1997; Labandeira 2002), bats (Caballero-Martínez et al. 2009), and honey possums (Bradshaw and Bradshaw 2001). However, it is likely that pollen has been underestimated in terms of its value as a reward for mammals, and there are suggestions that it is accidentally ingested during grooming or after visiting flowers to consume nectar (Wiens et al. 1983; Richardson et al. 1986). It is also thought that the cell wall may be inedible, thereby impeding digestion of the nutrient-rich cytoplasm (Stanley and Linskens 1974). Nonetheless, the honey possum *Tarsipes rostratus* presented significant digestion of pollen grains, and the quantity of empty pollen grains in the feces increased with more time in the intestine (Richardson et al. 1986). Moreover, it has been found that pollen can satisfy much of the nutrient requirements of the pygmy possum *Cercartetus nanus* (van Tets and Hulbert 1999), and there is even evidence of a bat-pollinated tree species, whose flowers produce only pollen as a food reward for the bat *Phyllostomus hastatus* (see Gribel and Gibbs 2002).

Rodents present a diverse diet that confers many different ecological roles upon them, e.g., consumers of fruit, seeds, plants (Rey et al. 2002; Schnurr et al. 2004; López-Barrera et al. 2005) and fungi, predators of mollusks and insects (Golley et al. 1975; Mangan and Adler 2000; Hernández-Betancourt et al. 2005), degraders of material accumulated in soils (Golley et al. 1975), seed dispersers (Rey et al. 2002; Li and Zhang 2003), and pollinators (Lumer and Schoer 1986; Johnson et al. 2001; Kleizen et al. 2008). It is known that rodents consume floral structures and pollen, but they do not always act as pollinators (Rourke and Wiens 1977; Richards et al. 1984; van Tets 1997; García-Franco and Rico-Gray 1991).

In southern Africa, examination of fecal samples has shown pollen to be an important element in the rodent diet (van Tets and Nicolson 2001; Fleming and Nicolson 2002). Detection of pollen consumption by rodents has been based on the presence of pollen in the excreta, leading to suggestions that consumption was accidental while eating floral parts or grooming (Wester et al. 2009), or even when foraging for insects (Fleming and Nicolson 2003). However, Fleming and Nicolson (2002) reported an almost exclusively pollen-based diet for the Cape spiny mouse (*Acomys subspinosus*) during the winter in South Africa (pollen comprised up to 80 % of scat volume, the remainder consisted of bacteria, trap bait, and other plant material). In the present study, we describe mice from Central America deliberately seeking and consuming pollen of the bromeliad *Tillandsia macropetala* Wawra in the wild. We suggest that pollen may be used as a supplement to the diet of these rodents during the dry season, when food resources are scarce. We support this with direct observations of the feeding behavior.

Methods

Fieldwork was conducted from February to April 2011 on the "La Luciérnaga" ranch (19°31′12.90″N; 96°59′17.98″W) near the village of Rancho Viejo, municipality of Tlalnelhuayocan, central Veracruz, Mexico. The study took place in a fragment (88.33 ha) of tropical montane cloud forest, where the dominant trees are *Liquidambar macrophylla* Oerst and *Quercus* spp. The site is located at an altitude of 1,500 m asl, with an annual precipitation of 1,650 mm and an average annual temperature of 16 °C. Typically, three distinct seasons occur in this region: a relatively dry and cold season from October to March, a dry warm season from April to May, and a rainy warm season from June to September (Williams-Linera 1997).

During a study of the reproductive biology in a population of *T. macropetala*, an epiphytic bromeliad species that exhibits nocturnal anthesis (for species description see Krömer et al. 2012), we recorded nocturnal visitors to the plants, from March 9 to April 16, 2011 (end of the dry and cold season and beginning of the dry warm season), using a video camera in night vision mode (Sony DCR-SR65; Sony Corporation, Japan), equipped with an infrared flash (HVL-HILR; Sony Corporation, Japan), set at a height of 1.3–1.5 m on a tripod and a distance of 0.5–1 m from the subject flowers.

We noted signs of possible rodent florivory in some of the studied bromeliads and therefore set 12 Sherman traps (8×9× 23 cm) over 2 nights (9 and 15 April 2011). Traps were baited with oats and vanilla essence and placed at the foot of trees on which the bromeliads presenting the most damage were located. A young female individual of *Peromyscus beatae* was captured at the foot of a tree on which a

bromeliad had undergone florivory on the same night, and samples of the gastric contents of this mouse were taken to search for traces of pollen (Richards et al. 1984) and to compare these with samples obtained from the anthers of *T. macropetala*. Gastric contents and excreta were both preserved in 70 % ethanol (Kleizen et al. 2008) for subsequent preparation and examination under a microscope (Carl Zeiss, Germany) at ×40 magnification. Mice specimens were deposited at the Zoological Collection of the Institute of Biological Research, Universidad Veracruzana, Mexico.

Results

All the observed *T. macropetala* individuals ($n=7$) presented signs of florivory, both in mature flowers and buds (Fig. 1), throughout the final week of March until the second week of April. Initial observations revealed that only the anthers and pollen were consumed, as the filaments only presented bite marks, and anther fragments were found without pollen below and/or among the leaves of the bromeliad. This pattern was also found in the apex of the buds, where the part of the petals covering the anthers was damaged, even 12 h before the buds opened (Fig. 1). By the end of the observation period, we found that at least 25 floral buds had been consumed.

We recorded ca. 100 flowers in seven bromeliads in 29 h, with the phyllostomid bat *Anoura geoffroyi* (Chiroptera: Phyllostomidae) observed to be the sole pollinator and the most frequent floral visitor (P. A. Aguilar-Rodríguez, unpublished data). However, during a video recording made on April 7, 2011 (the start of the dry warm season), we observed two incidences of mice repeatedly visiting the spikes of the inflorescence of one *T. macropetala*, between 1930 and 2240 hours (the first visits occurred between 2020 and 2240 hours, and the second between 2140 and 2,150 hours; Supplementary Video). On analysis of the video recording, we identified the mice as belonging to the genus *Peromyscus*. The mice were observed consuming pollen on the anthers (Fig. 2) and discarded the filaments. They did not consume nectar, even though this was highly abundant (434±178 μL, $n=21$ flowers). The bite marks left on the flowers by the mice were consistent with those observed on previous nights, as well as those observed on subsequent nights.

Ten individuals (five per night) were captured in the Sherman traps: *Reithrodontomys mexicanus* Saussure 1860 (one individual), *Peromyscus furvus* Allen and Chapman 1897 (one individual), *Peromyscus leucopus* Rafinesque 1818 (one individual), and *P. beatae* Thomas 1903 (seven individuals). From a total of 12 samples, taken from the single captured female *P. beatae* (six from gastric contents and six from excreta), no pollen grains were found.

Fig. 1 *Tillandsia macropetala* floral structures. Comparison between an undamaged flower and the two most common signs of florivory observed in the field. **a** Intact flower. **b** Flower with depredated anthers, with only the filaments remaining. **c** Floral buds with bite marks and anthers removed

Fig. 2 *Peromyscus* sp. feeding on the anthers of *Tillandsia macropetala*. A filament can be seen held in the front paws of the rodent

Discussion

Since *P. beatae* was the most frequently captured species and the female was found in close proximity to a damaged inflorescence, it is likely that this species was the main or only pollen consumer recorded at the study site, even if we did not find pollen grains in the feces. It is known that the species of the genus *Peromyscus* are pollinators of *Blakea* spp. (Melastomataceae) and that they obtain nectar as a reward (Lumer and Schoer 1986). However, in this study, the mice did not pollinate the bromeliad since no contact with the stigma is seen in the video, and most of the evidence of anther consumption was found in the floral buds. This indicates that pollen, rather than nectar, was the primary food supply sought by the mice.

Flowering of *T. macropetala* at the study site mainly occurs during the dry and cold season, a phenological pattern also presented by other plant species whose flowers are visited by

rodents, such as *Tillandsia deppeana* (García-Franco and Rico-Gray 1991), *Protea humiflora* (Proteaceae) (van Tets 1997; Fleming and Nicolson 2002), and *Massonia depressa* (Hyacinthaceae) (Johnson et al. 2001). African rodents (e.g., *Aethomys namaquensis*, *Rhabdomys pumilio*) that pollinate *Protea* spp. are seasonal nectarivores since they consume foliage and seeds for most of the years (van Tets and Nicolson 2001) but utilize pollen as a supplement to improve body condition prior to the breeding season (Fleming and Nicolson 2002). Our observations suggest that the mice in our study site could be similarly opportunistic consumers of pollen in flowers that become available during the beginning of the dry season when other resources are scarce.

As flowering of *T. macropetala* in the study site lasts for several weeks, and the plants generally open one flower per night, the pollen of this bromeliad species represents an available resource for opportunistic mice. Plants that present nocturnal anthesis, such as *T. macropetala*, coincide with the pattern of activity of rodent species. Moreover, the flower produces a conspicuous odor that can be detected over long distances (Kleizen et al. 2008).

Although recognition of pollen as part of the diet of vertebrates has increased (van Tets 1997; van Tets and Nicolson 2001; Caballero-Martínez et al. 2009), particularly in the case of African rodents, the importance of pollen as a resource must be evaluated in other ecosystems. An understanding is required on the importance of pollen and other floral resources in the diet of rodents during periods of low productivity and/or during reproduction and rearing of young. It is equally important to understand the impact of florivory on the reproductive success of plants since the consumption of pollen obviously reduces its availability for pollination (Bustamante et al. 2010), while the destruction of buds negatively impacts floral display and subsequent visitation by pollinators (Canela and Sazima 2003), which ultimately may affect bromeliad fecundity (Winkler et al. 2005).

References

Bradshaw FJ, Bradshaw SD (2001) Maintenance nitrogen requirement of an obligate nectarivore, the honey possum, *Tarsipes rostratus*. J Comp Physiol B 171:59–67

Bustamante E, Casas A, Búrquez A (2010) Geographic variation in reproductive success of *Stenocereus thurberi* (Cactaceae): effects of pollination timing and pollinator guild. Am J Bot 97:2020–2030

Caballero-Martínez LA, Rivas-Manzano IV, Aguilera-Gómez LI (2009) Hábitos alimentarios de *Anoura geoffroyi* (Chiroptera: Phyllostomidae) en Ixtapa del Oro, Estado de México. Acta Zool Mex 25:161–175

Canela MBF, Sazima M (2003) Florivory by the crab *Armases angustipes* (Grapsidae) influences hummingbird visits to *Aechmea pectinata* (Bromeliaceae). Biotropica 35:289–294

Fischer EA, Duarte LFL, Araujo AC (1997) Consumption of bromeliad flowers by the crab *Metasesarma rubripes* in a Brazilian coastal forest. Crustacean 70:118–123

Fleming PA, Nicolson SW (2002) How important is the relationship between *Protea humiflora* (Proteaceae) and its non-flying mammal pollinators? Oecologia 132:361–368

Fleming PA, Nicolson SW (2003) Arthropod fauna of mammal-pollinated *Protea humiflora*: ants as an attractant for insectivore pollinators? Afr Entomol 11:9–14

García-Franco JG, Rico-Gray V (1991) Biología reproductiva de *Tillandsia deppeana* Steudel (Bromeliaceae) en Veracruz, México. Brenesia 35:61–79

Golley FB, Ryszkowski L, Sokur JT (1975) The role of small mammals in temperate forest, grasslands and cultivated fields. In: Golley FB, Petrusewicz K, Ryszkowski L (eds) Small mammals: their productivity and populations dynamics. Cambridge University Press, Cambridge, pp 223–242

Gribel R, Gibbs PE (2002) High outbreeding as a consequence of selfed ovule mortality and single vector bat pollination in the Amazonian tree *Pseudobombax munguba* (Bombacaceae). Int J Plant Sci 163:1035–1043

Hernández-Betancourt SF, Gómez-González J, Cimé-Pool JA, Medina-Peralta S, Euán-Canul CM (2005) First report of use of land snails for *Heteromys gaumeri* (Rodentia: Heteromyidae) in a subdeciduous forest in Yucatán, México. Acta Zool Mex Nueva Serie 21:155–156

Johnson SD, Pauw A, Midgley J (2001) Rodent pollination in the African Lily *Massonia depressa* (Hyacinthaceae). Am J Bot 88:1768–1773

Kearns CA, Inouye DW (1993) Techniques for pollination biologists. University of Colorado Press, Colorado

Kleizen C, Midgley J, Johnson SD (2008) Pollination systems of *Colchicum* (Colchicaceae) in Southern Africa: evidence for rodent pollination. Ann Bot London 102:747–755

Krömer T, Espejo-Serna A, López-Ferrari A, Ehlers E, Lautner J (2012) Taxonomic and nomenclatural status of the Mexican species in the *Tillandsia viridiflora* complex (Bromeliaceae). Acta Bot Mex 99:1–20

Labandeira CC (2002) The history of associations between plants and animals. In: Herrera CM, Pellmyr O (eds) Plant-animal interactions: an evolutionary approach. Blackwell, Oxford, pp 26–74

Li HJ, Zhang ZB (2003) Effect of rodents on acorn dispersal and survival of the Liaodong oak (*Quercus liaotungensis* Koidz.). Forest Ecol Manag 176:387–396

López-Barrera F, Newton A, Manson R (2005) Edge effects in a tropical montane forest mosaic: experimental tests of post-dispersal acorn removal. Ecol Res 20:31–40

Lumer C, Schoer RD (1986) Pollination of *Blakea austin-smithii* and *B. penduliflora* (Melastomataceae) by small rodents in Costa Rica. Biotropica 18:363–364

Mangan SA, Adler SH (2000) Consumption of arbuscular mycorrhizal fungi by terrestrial and arboreal small mammals in a Panamanian cloud forest. J Mammal 81:563–570

Rey PJ, Garrido JL, Alcántara JM, Ramírez JM, Aguilera A, Farcía L, Manzaneda AJ, Fernández R (2002) Spatial variation in ant and rodent post-dispersal predation of vertebrate-dispersed seeds. Funct Ecol 16:773–781

Richards CGJ, White AC, Hurrell E, Price FEF (1984) The food of the common dormouse, *Muscardinus avellanarius*, in South Devon. Mammal Rev 14:19–28

Richardson KC, Wooler RD, Collins BG (1986) Adaptations to a diet of nectar and pollen in the marsupial *Tarsipes rostratus* (Marsupialia: Tarsipedidae). J Zool 208:285–297

Rourke JP, Wiens D (1977) Convergent floral evolution in South African and Australian Proteaceae and its possible bearing on pollination by nonflying mammals. Ann Mo Bot Gard 64:1–17

Schnurr JL, Canham CD, Ostfeld RS, Louye RS (2004) Neighborhood analyses of small-mammal dynamics: impacts on seed predation and seedling establishment. Ecology 85:741–755

Stanley RG, Linskens HF (1974) Pollen: biology, biochemistry and management. Springer, Berlin

Van Tets IG (1997) Extraction of nutrients from *Protea* pollen by African rodents. Belg J Zool 127:59–65

Van Tets IG, HULBERT AJ (1999) A comparison of the nitrogen requirements of the eastern pygmy possum, *Cercartetus nanus*, on a pollen and on a mealworm diet. Physiol Biochem Zool 72:127–137

Van Tets IG, Nicolson SW (2001) The nutritional ecology of rodent pollinators of *Protea* in South Africa. In: Denys C, Granjon L, Poulet A (eds) African small mammals. Editions de I'IRD, Paris, pp 311–320

Wester P, Stanway R, Pauw A (2009) Mice pollinate the Pagoda Lily, *Whiteheadia bifolia* (Hyacinthaceae). First field observations with photographic documentation of rodent pollination in South Africa. S Afr J Bot 75:713–719

Wiens D, Rourke JP, Casper BB, Rickart EA, Lapine TR, Peterson CJ, Channing A (1983) Nonflying mammal pollination of southern African *Proteas*. Ann Mo Bot Gard 70:1–31

Williams-Linera G (1997) Phenology of deciduous and broadleaved-evergreen tree species in a Mexican tropical lower montane forest. Global Ecol Biogeogr 6:115–127

Winkler M, Hülber K, Mehltreter K, García-Franco J, Hietz P (2005) Herbivory in epiphytic bromeliads, orchids and ferns in a Mexican montane forest. J Trop Ecol 21:147–154