Diversity of Wild Bees and their Mediated Dispersal of Pollen from the Genus Tillandsia (Bromeliaceae, Tillandsioideae) in an Insular Area

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A total of 98 bees were collected, belonging to six genera and seven species in flowers of Tillandsia stricta and T. tenuifolia. The bees displayed similar foraging behaviors, visiting flowers in search of nectar, except for Trigona spinipes, which collected pollen in addition to nectar. In some species, as was the case of Bombus atratus and B. morio, most of the pollen was concentrated in the head and thorax. Pollen of the two Tillandsia species were dominant amongst pollen types found on the bees. Specimens of B. atratus, B. morio and T. spinipes, found on the flowers of T. stricta, presented 100% pollen from that plant. Bombus atratus specimens visiting T. tenuifolia, presented 90% pollen from that source and 10% from Mimosa pudica, thus revealing the vertical foraging behavior of this bee species. Bees that visit T. tenuifolia e T. stricta on their flowering are potential dispersers of their pollen.

Keywords: *Apoidea, Diversity, Foraging, Palynology, Pollen.*

Introduction

Most tropical botanical species need to be animal pollinated (Vogel, 1983; Bawa, 1990). Bees (Hymenoptera: Apoidea) have a close relationship with Angiosperms that could be based on mutual benefits (Ricketts, 2004, Winfree et al., 2008, Klatt et al., 2013). Normally, flowers are visited because they offer nectar, pollen, oils and fragrances that can be used by adult bees or their young, depending on the resource. Some species use flowers as shelter, places for repose or for breeding, and in exchange plants are pollinated (Simpson and Neff, 1981; Vogel, 1983; Kevan and Baker, 1983; Pesson, 1984; Roubik, 1989; Proctor et al., 1996; Pedro and Camargo, 1999). This relationship is seen as an obligatory interaction for both parties and varies in the degree of specialization (Laroca et al., 1989).

Studies that address the pollination ecology of the Bromeliaceae species show that hummingbirds are their principal pollinators (Benzing, 1980; Siqueira-Filho and Machado, 2001; Araújo et al., 2004; Zanella et al., 2012; Missagia and Alves, 2015), while some kinds of bees can act as effective pollinators (Fischer, 1994; Almeida et al., 2004), eventual pollinators or nectar thieves (Siqueira-Filho and Machado, 2001). Martinelli (1997) considered

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Entomophily uncommon in the Bromeliaceae. However, several studies suggest that insects do pollinate this family of plants (Benzing, 1980; Gardner, 1986; Varadarajan and Brown, 1988; Till, 1992; Almeida et al., 2004).

Some studies that focus on the palynology aspects of the relationship between plants and their vectors, show that pollen grains adhered to the foraging animal bodies can be used to infer floral preferences and how it varies in time and space (Absy and Kerr, 1977; Imperatriz-Fonseca et al., 1989; Ramalho et al., 1994; Hesse, 2000; Barros et al., 2000; Amaya et al., 2001, Lasprilla, 2003). Palynology, supported by ecological and behavioral studies, helps clarify the relationships of interdependence that exists between plants and their pollinators, between nectar and pollen consuming herbivores and the plants that supply these resources. The characterization of pollen not only allows for the ornamental differences of the grains to be known, thus facilitating the taxonomic classification of plant species, but also enables the identification of pollen grains that adhere to the bodies of flower visitors in pollination studies. This helps in the identification of eventually important vectors of pollen.

In the forests of Ilha Grande (an island in the Southern coast of Rio de Janeiro State and one of the largest remnants of the Brazilian Atlantic Rainforest - it is the 5th largest oceanic island along Brazilain coast), a high richness of bromeliad species occur – at least 59 species (Nunes-Freitas et al., 2009), with different pollination strategies and pollinators. Among these, 11 species from the genus *Tillandsia* (Tillandsioideae) can be found, with *T. stricta* and *T. tenuifolia* being relatively frequent and occurring sympatrically in some portions of the forest.

The hypothesis is that the presence of bees in *T. stricta* and *T. tenuifolia* flowers promote them as possible pollinators by contamination on their bodies by pollen grains of these two bromeliads.

The aim of this work was to identify bee species found on the flowers of *Tillandsia stricta* Sol. ex Sims and *Tillandsia tenuifolia* L. and to quantify the pollen types adhered to the bees' bodily structures. This can reveal which bee species are potential dispersers for the pollen of the Bromeliaceae plants.

Materials and Methods

Sampling was carried out in Ilha Grande (23°11' S e 44°12' W), an island that belongs to the state of Rio de Janeiro, Brazil. Bees were collected during the flowering period of 2004 to 2005 of *T. stricta* (peak flowering – January) and *T. tenuifolia* (peak flowering – February), at three places that had been previously demarcated for each of these species. At each site during the antesis period of each of the bromeliad species we sampled bee species visiting flowers during 30 minutes at each 15 minutes interval, totaling 80 hours of sampling for *T. stricta* and 88 sampling hours to *T. tenuifolia*.

Collected specimens were identified, stored in bottles, and later whatever pollen was present on their bodies was removed for analysis. The insects' bodies were thoroughly screened for pollen with the help of a stereo microscope. For each bee specimen, the following data was noted down: species, time of capture, number of the plant if was found on, foraging behavior and which body parts showed adhered pollen grains.

Pollen grains found on bees were processed at the Laboratory of Palynology of the Botany Department in the Federal University of Rio de Janeiro, according to the modified Wodehouse methodology (1935), in which the assemblage of pollen slides in glycerinated gelatin is direct and fast without resorting to acetolysis. Pollen grains found on the bodies of individuals from each bee species were pooled together, and three slides were mounted from each sample so that pollen types could be observed and counted under the optical microscope.

The analysis consisted of registering the presence or absence of pollen from *T. stricta* and/or *T. tenuifolia* and of counting the total number of pollen grains from different pollen types found in the samples (Barth, 1989). Pollen types were then classified in four categories according to their frequency: dominant pollen (>45%), accessory pollen (15-44%), important isolated pollen (3-14%) and occasional isolated pollen (<3%) (Zander, 1935; Barth, 1989). We employed the terminology of Barth and Melhem (1988) and Punt et al. (2007) glossaries, and for statistical analysis the arithmetic mean and standard deviation of the mean were used.

Results and Discussion

A total of 98 bees were collected, belonging to six genera in the Apidae family (*Bombus*, *Cephalotrigona*, *Geotrigona*, *Melipona*, *Paratrigona* e *Trigona*) and one genus in the Halictidae family (*Dialictus*) (Table 1). Bee species that had *T. stricta* pollen grains adhered to their bodies were: *Bombus morio* Sweederus, *Bombus atratus* Franklin, *Trigona spinipes* Fabricius, *Melipona quadrifasciata* Lepeletier, *Cephalotrigona capitata* Smith and *Paratrigona lineata* Lepeletier. While pollen grains from *T. tenuifolia* were found on the bodies of *B. morio, B. atratus, T. spinipes, Geotrigona* sp., *C. capitata*, *P. lineata* and *Dialictus* sp. (Table 2).

Field observations revealed that all bee species had similar foraging behavior, i.e. they would visit flowers looking for nectar and become impregnated with pollen from the flower’s anthers. The exception was *T. spinipes*, which at a certain time of the day, normally after 16:00, would specifically only collect pollen.

Some bee species, as *T. spinipes* and *C. capitata* would store pollen in the corbicula whatever pollen grains they had adhered to their bodies, so as to carry them back to the colony. The collecting and storing of Bromeliaceae pollen has also been observed in three species of *Vriesea* by Araújo et al. (1994; 2004), in *Aechmea cylindrata* Lindman (Kaehler, 2005), in *Canistrum aurantiacum* E. Morren (Siqueira-Filho and Machado, 2001), in *Aechmea* *beeriana* Smith & Spencer (Nara and Webber, 2002) and in *Pitcairnia flammea* L. (Rocha-Pessôa and Rocha, 2008).

Table 1. *Presence of Adhered Pollen Grains in the Bodies of Bees (Hymenoptera: Apoidea) Collected from the Flowers Tillandsia stricta Sol. ex. Sims and Tillandsia tenuifolia L. (Bromeliaceae, Tillandsioideae), Ilha Grande, Rio de Janeiro, Brazil. n.a.= number*

Species	Family	Plant visited	n.a. of visiting bees	Mean and standard deviation
Bombus atratus	Apidae	*Tillandsia stricta*	12	86.3 ± 6.5
		Tillandsia tenuifolia	10	110.5 ± 5.9
Bombus morio	Apidae	*Tillandsia stricta*	10	93.8 ± 8.1
		Tillandsia tenuifolia	09	125.4 ± 10.9
Trigona spinipes	Apidae	*Tillandsia stricta*	16	38.5 ± 2.7
		Tillandsia tenuifolia	10	48.0 ± 5.0
Melipona quadrifasciata	Apidae	*Tillandsia stricta*	05	58.0 ± 2.9
Cephalotrigona capitata	Apidae	*Tillandsia stricta*	06	67.0 ± 4.0
		Tillandsia tenuifolia.	04	88.0 ± 1.7
Paratrigona lineata	Apidae	*Tillandsia stricta*	05	62.2 ± 2.3
		Tillandsia tenuifolia	03	38.3 ± 2.7
Geotrigona sp.	Apidae	*Tillandsia tenuifolia*	04	67.0 ± 2.8
Dialictus sp.	Halictidae	*Tillandsia tenuifolia*	04	55.5 ± 3.3
Total	--	--	98	--

Pollen is the main source of nitrogen for bees and it is extensively collected in flowers and then stored in honeycombs or wax pots, depending on the species, to supply the dietary needs of the colony (Roubik, 1989). Different methods of research in palynology have been used to evaluate the source of floral resources and their use as a food by the hymenoptera (Engel and Dingemans-Bakels, 1980; Absy et al., 1984; Ramalho et al., 1989; Biesmeijer and Sommeijer, 1992; Eltz et al., 2001). The pollen found in bees that have visited flowers of *T. stricta* and of *T. tenuifolia*, shows that these insects do indeed collect pollen in these Bromeliaceae (Table 1).

Some studies show that the size of the bees' bodies, the morphology of flowers and the foraging behavior of bees all play a part in determining the capacity for pollination, the transference of some of the pollen to the receptive stigma of the flower (Janzen, 1968; Varassin and Silva, 1999).

Pollen grains were found to adhere to all parts of the bees' bodies, but in species of the *Bombus* genus, the majority of pollen was concentrated on the head and thorax, probably due to their body size. *Paratrigona lineata* bees are smaller than their *Bombus* counterparts and after landing in the corolla's apex, they would enter the flowers of both *Tillandsia* species through the stamens, towards the nectary at the base of the corolla. This action involved touching the flower's anthers, which means the bee's belly was impregnated with a significant number of pollen grains, while its' back remained in contact with the internal wall of the corolla. *Cephalotrigona capitata* bees showed

Tillandsia pollen grains on their heads, thorax and abdomen, which indicates contact with the anthers of these plants.

Table 2. *Percentage of Pollen Types Found in Bees Visiting the Flowers of Tillandsia stricta Sol. ex Sims and Tillandsia tenuifolia L. (Bromeliaceae: Tillandsioideae), Ilha Grande, Rio de Janeiro, Brazil. n.a.= number*

Species	*Tillandsia* visited	Pollen type	n.a. of adhered pollen grains	%
Bombus atratus	*Tillandsia stricta*	*Tillandsia stricta*	1035	100
	Tillandsia tenuifolia	*Tillandsia tenuifolia*	1105	90
		Mimosa pudica	123	10
Bombus morio	*Tillandsia stricta*	*Tillandsia stricta*.	938	100
	Tillandsia tenuifolia	*Tillandsia tenuifolia*	1129	100
Trigona spinipes	*Tillandsia stricta*	*Tillandsia stricta*	616	100
	Tillandsia tenuifolia	*Tillandsia tenuifolia*	480	100
Melipona quadrifasciata	*Tillandsia stricta*	*Tillandsia stricta*	290	80
		Asteraceae	62	17
		Lantana camara	11	11
Cephalotrigona capitata	*Tillandsia stricta*	*Tillandsia stricta*	402	85
		Asteraceae	71	15
	Tillandsia tenuifolia	*Tillandsia tenuifolia*	352	92
		Asteraceae	31	8
Paratrigona lineata	*Tillandsia stricta*	*Tillandsia stricta*	311	95
		Mimosa pudica	13	4
	Tillandsia tenuifolia	*Lantana camara*	3	1
		Tillandsia tenuifolia	115	60
		Asteraceae	57	30
		Verbenaceae	19	10
Geotrigona sp.	*Tillandsia tenuifolia*	*Tillandsia tenuifolia*	268	96
		Bignoniaceae	11	4
Dialictus sp.	*Tillandsia tenuifolia*	*Tillandsia tenuifolia*	222	85
		Asteraceae	26	10
		Lantana camara	13	5

Observation of the frequency of visitation, resource availability in the plant and exploration behavior of the floral vectors can help distinguish between principal pollinators, occasional pollinators and nectar thieves (Machado and Sazima, 1995; Sigrist and Sazima, 2002). The pollen load that the vector carries and the body part where it carries it can, also be indicators of the efficiency of pollinators, whenever the pollen grains and the stigma come into contact. Some studies of palynology concerning plants and their vectors were discussed in Barros et al. (2000), Amaya et al. (2001) and Lasprilla

(2003). *Phyllostomus hastatus* Pallas (Mammalia: Phyllostominae) was cited as being an occasional (opportunist) pollinator of *Pseudobombax* sp. (Bombacaceae) because of the amount of pollen found on their fur and also because of their morphology (Barros et al., 2000). Plant-hummingbird interactions have also been evidenced through the observation of pollen in different parts of the bodies of species of the Trochilidae family (Amaya et al., 2001; Lasprilla, 2003; Capucho et al., 2007). Lasprilla (2003) analyzed pollen found in species of the Phaethornithinae and Trochilinae subfamilies and reckoned that beak size can greatly influence the amount and diversity of the resources carried by the hummingbirds, with long-beaked (less territorial) species showing greater pollen diversity than species with smaller beaks (more territorial).

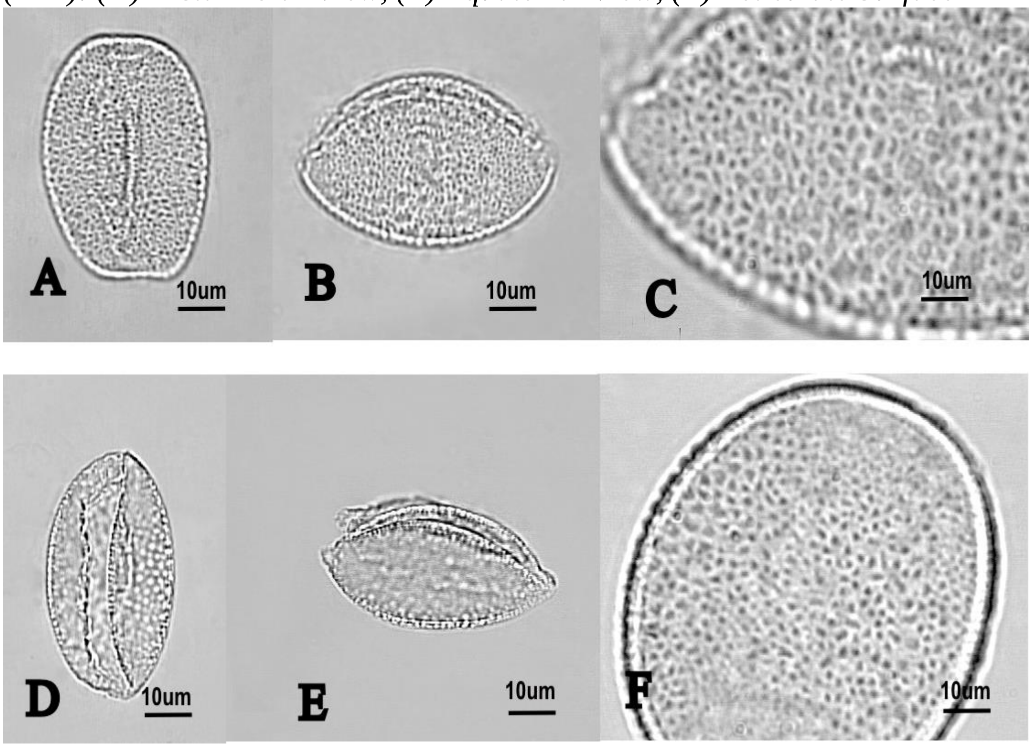
Our research revealed that *B. atratus* and *B. morio* bees manage to reach the stigma in the flowers of *T. stricta* and *T. tenuifolia*, during which process their heads and thoraxes are impregnated with pollen. Native stingless bees such as *T. spinipes*, *M. quadrifasciata*, *C. capitata* e *P. lineata*, go through the same process. *Bombus morio* and *B. atratus* bees showed the highest values of pollen grains from both *Tillandsia* species, while *T. spinipes* had the lowest mean for *T. stricta* pollen and *P. lineata* the lowest mean for pollen of *T. tenuifolia* (Table 1). This data can be explained by the body sizes of different species.

According to the percentage of pollen types present in the bodies of bees, pollen grains from *Tillandsia* (Figure 1) were classified as dominant pollen, while that of *Lantana camara* L. (Verbenaceae) was present in less than 1% of the studied specimens, thus being classified as occasional isolated pollen (Table 2). The Asteraceae pollen type was classified as accessory in all pollen samples. On the other hand, the Bignoniaceae pollen type was only found in bees of the *Geotrigona* genus and ranked as important isolated pollen in that sample (Table 2). The amount of pollen types and their respective proportions in bee species that visited the two *Tillandsia* plants are an indication of existing differences amongst bees in terms of fidelity to floral resources offered by these two Bromeliaceae (Table 2).

Bees from the *Bombus* and *Trigona* genera found on the flowers of *T. stricta* showed 100% pollen from that source. Meanwhile, *B. atratus* bees found on the flowers of *T. tenuifolia*, showed 90% pollen from that source and 10% pollen from *Mimosa pudica* L. (Leguminosae: Mimosoideae), revealing this species' vertical foraging behavior, for *M. pudica* is a herbaceous and prostrate plant (Lorenzi, 2000).

The ornaments on the surface of pollen grains can help characterize the vector type that promotes their dispersal. In this case, both *Tillandsia* species display a reticulated surface (Figure 1), which is known to be a typical ornamentation for vectors like bees (Hesse, 2000).

Figure 1. *Pollen Grains of Tillandsia stricta Sol. ex Sims and Tillandsia tenuifolia L. (Bromeliaceae: Tillandsioideae). Tillandsia stricta (A-C): (A) Distal Polar View, (B) Equatorial View, (C) Reticulate Surface; T. tenuifolia (D-F): (D) Distal Polar View, (E) Equatorial View, (F) Reticulate Surface*



Conclusions

Bee species that collected pollen from *T. stricta* and *T. tenuifolia* showed potential to act as dispersers of pollen for those plants and therefore qualify as occasional or possibly effective pollinators of these plants and eventually other local species in the Bromeliaceae family, which is a new finding. Species like *B. morio* and *T. spinipes* showed 100% pollen from those plants adhered to their bodies and revealed a preference in certain times of day for the resources (pollen and/or nectar) offered by the plants. The analysis of the pollen grains adhered to the foraging insects' bodies allowed for some insight on their floral preferences as well as on how it varies in time and space, specifically in an insular area with particular characteristics. Therefore, Palynology, together with ecological and behavioral studies, can have a decisive role in elucidating the mechanisms of interdependence between these organisms (bees and plants).

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