Short communication

Visiting and feeding behavior of sap beetles (*Carpophilus lugubris*) in the flowers of a chiropterophilic columnar cactus (*Pilosocereus leucocephalus*)

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ABSTRACT

*Carpophilus* beetles have been observed in the flowers of some chiropterophilic columnar cacti. However, the visiting and feeding behavior of these beetles in these flowers has not been described in detail. Here, we describe for the first time the visiting and feeding behavior of *Carpophilus lugubris* in the flowers of *Pilosocereus leucocephalus*, a chiropterophilous columnar cactus, in a tropical dry forest in central Veracruz, Mexico. *C. lugubris* was found in 100% of the flowers examined, with a mean of 70.54 ± 9.44 beetles per flower (range: 2–267). Up to three beetles were seen in 37% of the buds examined, therefore *C. lugubris* can enter the flower before anthesis. *C. lugubris* was not observed touching the stigma during the study, suggesting that this beetle may have a limited role in pollination. The nectar of *P. leucocephalus* was found in the beetles’ guts, but there was no pollen, suggesting that *C. lugubris* consumed only nectar. The flowers of *P. leucocephalus* were also used as mating sites by *C. lugubris*.

The cactus family is completely animal-pollinated, with bees, birds and bats the main pollen vectors (Rowley, 1980). Although beetle pollination has not been described in Cactaceae, sap beetles (*Carpophilus* sp., Nitidulidae) frequently visit the flowers of several cactus species across the Americas (e.g. Bowers 2002; Ordones-Regó et al., 2002; Agüero et al., 2018) where up to 100 beetles can be found together in a single flower (Grant and Connell, 1979). Sap beetles are often disregarded as pollinators because they rarely touch the stigmas, however they are considered pollen/nectar robbers (e.g. Agüero et al., 2008; Figueroa-Castro et al., 2014). This dual role—robber and incidental pollinator—has also been reported in the flowers of cacti primarily pollinated by vertebrates and bees (Grant and Connell, 1979). Non-trophic interactions between beetles and the flowers they visit are also common. For instance, beetles use the flowers as mating sites and for thermal regulation (Bernhardt, 2000).

The study of beetle-flower interactions is challenging. Beetles spend far longer periods (from hours to days) in the innermost part of the flower (Bernhardt, 2000) than any of the primary cactus pollinators. Therefore, the traditional approaches used to assess the behavior of floral visitors to cacti may be ineffective for beetles. A proper assessment of the feeding behavior of these beetles requires longer observation periods, invasive techniques such as flower dissection (Bernhardt, 2000), and/or gut-content analyses of the beetles (Johnson and Nicolson, 2001). For nocturnal species, nocturnal vision devices are required (Munguía-Rosas et al., 2010).

*Carpophilus* beetles visit the flowers of some chiropterophilic columnar cacti (*Carnegiea gigantea* [Olson, 2000], *Pachycereus weberi* [Figueroa-Castro et al., 2014]), and have been found in the stomachs of *Leptonycteris* bats, one of the most important pollinators of columnar cacti in North America (Howell, 1974). Chiropterophilic and cantharophilic flowers share several traits, such as nocturnal anthesis, pale color, fermentation odor and a relatively large size (Bernhardt, 2000), and this may explain why these beetles are so common in the flowers of chiropterophilic cacti. However, details on the feeding behavior of sap beetles are limited and the role they play during their visits to columnar cactus flowers is not known. Therefore, our goal was to describe the visiting and feeding behavior of the sap beetle *C. lugubris* in the flowers of *Pilosocereus leucocephalus*, a chiropterophilous columnar cactus.

The population of *P. leucocephalus* we studied is located in central Veracruz, Mexico (19° 35’ 20” N, 96° 50’ 38” W, 950 m a.s.l.). Vegetation is tropical dry forest, mean annual temperature is 24 °C and rainfall 519 mm. *P. leucocephalus* produces bell-shaped, pale,
hairs in A, and the chewing mouthpart in B.

Fig. 1. Dorsal (A) and ventral (B) view of the Carpophilus lugubris beetles that visited the flowers of P. leucocephalus in central Veracruz, Mexico. Note the hairs in A, and the chewing mouthpart in B.

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In contrast to some Scarabaeidae beetles (Peringuey, 1902), *C. lugubris* has no specialized structures for sucking nectar (Fig. 1B), which may indicate that *C. lugubris* is not a specialized nectar feeder. As occurs in other *Carpophilus* species that visit cactus flowers (Grant and Connell, 1979; Agüero et al., 2018), *C. lugubris* does not usually touch the stigma of the flowers of *P. leucocephalus*. This is probably because the stigma does not provide any resource to these beetles, and it is ca. 60 mm away from the nectar chamber (Munguía-Rosas et al., 2010) where *C. lugubris* typically is found. Therefore, venturing from the nectar chamber to the stigma is clearly not cost-effective.

Although we did not see any pollen grains on the beetles collected, these insects do have some hairs on their body (Fig. 1) and thus, may have the ability carry pollen grains. However, the quantity of pollen they might deposit on the stigma would be low, not only because pollen transport seems to be infrequent, but also because no contact with the stigma has been observed (neither in videos nor during nonsystematic observation). This leads us to think that *C. lugubris* plays a limited role as pollinator of *P. leucocephalus*, if any. On the other hand, if *C. lugubris* consumes nectar with little or no contribution to the plant’s reproductive success, it could be considered a nectar robber. While robbing nectar may have a negative impact on sexual reproduction by disturbing pollinator visiting behavior, the final effect on plant reproduction depends on visit frequency and the amount of nectar consumed. Some studies have found a neutral or even positive effect of nectar robbing in other plant species (Maloof and Inouye, 2000). However, we think that the effect of robbing nectar by *C. lugubris* has only a minor effect on the activity of bat pollinators. Up to 2.5 ml of nectar is produced by *P. leucocephalus* flowers and it is replenished several times in one night after being removed (Munguía-Rosas et al., 2010). The gut of *C. lugubris* is less than 60 μm long, so it is unlikely that this beetle can consume all of the available nectar. Furthermore, sap beetles may have a positive effect on visits by bat pollinators, since beetles and other insects represent a valuable source of protein for nectarivorous bats (Herrera et al., 2001). It is also known that *Carpophilus* beetles are a yeast vector and produce a fermentation odor that is attractive to some pollinators, such as bats (Pozo et al., 2014). However, further research is needed to assess whether *C. lugubris* and/or their associated yeast play a role in pollinator attraction.

In conclusion, *C. lugubris* uses the flowers of *P. leucocephalus* as feeding source (nectar) and as a mating site. Although our results suggest that *C. lugubris* has little impact on the reproductive success of *P. leucocephalus* as a pollinator and/or nectar robber, these topics deserve further attention.

Credit author statement

FF-T and AM-J designed the study and performed the fieldwork, MAM-R analyzed the data and wrote the first draft. All of the authors revised and approve of the final version of the manuscript.

CRediT authorship contribution statement

**Antonio Miranda-Jácome:** designed the study and performed the fieldwork. All of the authors revised and approve of the final version of the manuscript. **Fatima Fernandez-Tlapa:** designed the study and performed the fieldwork. All of the authors revised and approve of the final version of the manuscript. **Miguel A. Munguía-Rosas:** Formal analysis, Data curation, Writing – original draft, analyzed the data and wrote the first draft. All of the authors revised and approve of the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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