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Bee richness and abundance in small fruit farms from the semiarid landscape, NE, Brazil

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A B S T R A C T

Bee diversity and the status of native populations are barely known in cropland from semiarid Sergipe, where fruit production is a growing activity among small farmers. *Psidium guajava* L. (Myrtaceae) is spread among small farmers in Canindé de São Francisco and Poço Redondo in Sergipe state, Northeastern Brazil, in semiarid Caatinga, causing landscape change and habitat loss. Available evidence supports that cross-pollination provided by bees may increase seed set and fruit production, despite self-pollination. We aimed to access bee richness and abundance within the Guava orchard and identify landscape variables influencing them. The survey was conducted in ten Guava orchards during the flowering period (n=10) from May to December 2017. Nine bee species were recorded. No significant effect of landscape structure on richness was detected, maybe because of the low number of bee species recorded. The high-density and generalist bees *Trigona spinipes* and *Apis mellifera* comprised 92% of the flower visitors. No other social native bees were found, and solitary bees were scarce. Native bees that are habitat-sensitive (nesting in cavities on tree trunks) and specialized feeders are the losers. Bee abundance was affected by environmental diversity, isolation, and distance to Caatinga patches and continuous vegetation reserves. These results highlight the importance of the adequate management of natural or semi-natural pollinator habitats in the surrounding landscape. Conserving and restoring natural areas is recommended to provide nesting habitats, diversified flower sources, and connectivity within farmland to increase native bee populations, both solitary and social, within the Guava crop. Further studies linking landscape variables and the potential impact on the stability of crop pollination are needed.

Keywords: Agroecosystems, biodiversity, ecosystem services, *Psidium guajava*.

Introduction

The value of bees and the pollination services they provide in crop production has received increasing attention from national (BPBES/REBIPP, 2019) and international (IPBES, 2016) research forums and organizations (FAO, 2022). For 70% of tropical crop species, fruit production increased in at least one variety due to animal pollination (Roubik, 1995). Keeping the biodiversity of pollinating bees is a key condition to sustaining fruit production and the quality of crops (Giannini et al., 2015; Dainese et al., 2019). In farmlands from this study, at least other seven crop species associated with Guava, such as acerola, mango, passionfruit, coconut, and bean, may increase fruit production when pollinators are present (Klein et al., 2020). Despite being able to self-pollinate, native bees, either social or solitary, can improve fruit and seed set in guava (*Psidium guajava* L. cv. Paluma, Myrtaceae) (Klein et al., 2020). A previous survey, conducted in the same orchards as this study, recorded that fruit set increased by 7% in open flowers (natural pollination) in Guava orchards (Silva et al., 2019) while other studies, conducted in similar areas in the Brazilian semiarid, recorded about 12% (Siqueira et al., 2012) and 39% (Alves & Freitas, 2007) higher fruit set from open flowers in comparison to bagged flowers (not available to pollinators).

The current loss of pollination services in agroecosystems is linked to a decrease in the richness and abundance of native bee populations (Klein et al., 2007; Garibaldi et al., 2013). Such loss of bee diversity in farmland is linked to many causes, such as the synergistic and negative effects of habitat loss and conventional farming, mainly because of the use of agrochemicals and deforestation (Viana et al., 2014; Saunders et al., 2016; Carrié et al., 2017; Dicks et al., 2021) and the resulting simplification of agricultural landscapes (Dicks et al., 2021). Land use and land-cover changes (LULCC) are major drivers of biodiversity loss in semi-arid regions, such as the Caatinga biome, located in the Northeast of Brazil (Salazar et al., 2021), is considered a key factor affecting native species persistence in crop areas (Viana, 2008).

Throughout the range of the Caatinga biome, about 27% of its land cover has been converted into agricultural use, while only 2% comprises natural vegetation within protected areas (Castelletti et al., 2003). Agricultural expansion in Petrolina-Juazeiro over 33 years (1985–2018) increased at a mean rate of 2104 ha year^{-1}, while native Caatinga vegetation decreased at a mean rate of 5203 ha year^{-1}(Salazar et al., 2021). In Sergipe State, Caatinga covers 49% of the territory (Santos & Tabarelli, 2002), but deforestation increased by approximately 26% in semiarid Sergipe, partially due to growing regional economic activities based on firewood logging, subsistence crops (cassava, maize), and livestock provided by Caatinga vegetation (Fernandes et al., 2015).

National production of Guava (*Psidium guajava*), which is a Brazilian economically important tropical fruit due to its versatility of uses and nutritional value, reached 460.515 t, harvested from 20.206 ha in 2017 (IBGE, 2018). Due to irrigation, Guava crops are spreading among small farmers in Poço Redondo and Canindé do São Francisco. In 2017, in the semiarid Caatinga of Sergipe alone, production reached 8.480 t (5.5% of national production), harvested from 425 ha, presenting net productivity still below the national average (IBGE, 2018). In this local context, small farmers live in poor socioeconomic situations, and local settlements face the challenge to provide subsistence and well-being to farmers through a conventional system. Meanwhile, the spread of settlement areas with conventional agriculture threatens local biodiversity and ecosystem services, such as pollination by bees and pest control provided by predatory birds (Silva et al., 2019; Silva et al., 2021).

Although Africanized honeybees can pollinate Guava flowers, it is widely accepted that relying on a single pollinator species is risky and does not substitute other native bees (Garibaldi et al., 2013; Giannini et al., 2015; BPBES/REBIPP, 2019).

Despite the increasing number of evidence suggesting a negative effect of a landscape under agricultural intensification (Viana, 2008; Pretty, 2018), there is a lack of information linking landscape variables to bee abundance and density in farmland from Caatinga. This is the first attempt to analyze bee richness and abundance in the agroecosystem of semiarid Sergipe. In this study, we evaluated the effect of the surrounding landscape structure on bee abundance and richness within Guava crops. We expected an increasingly positive effect in Guava orchards surrounded by high amounts of nearby diversified native habitats. Data on bee species can support further investigations focusing on the potential impact of pollinator loss on Guava crops and actions to manage and conserve suitable habitats for native bees in this context.

Material and Methods

Study site

Data sampling was performed from May to December 2017 in the Municipalities of Canindé de São Francisco (09°39′36′′ S, 37°47′22′′ W) and Poço Redondo (09°48′18′′ S, 37°41′04′′ W), respectively, in Sergipe, Northeastern Brazil (Figure 1). The region is located within the semiarid with Caatinga as the main vegetation type (Andrade-Lima, 1981). The local climate is BSh type (local steppe), according to Köppen (1936). The mean annual temperature is 25-25.3C° and precipitation ranges between 521-548mm in the area (1982-2012) (CLIMATE DATA, 2019).

The most common management crop system is conventional, but some low-impact agronomic practices can be found, as described in Silva et al. (2019). We selected ten farms ranging from 2 to 22 ha the surveyed Guava orchards were 12 years old, and size ranged from 0.6 to 1 ha, with spacing between rows and lines greatly varying among them.

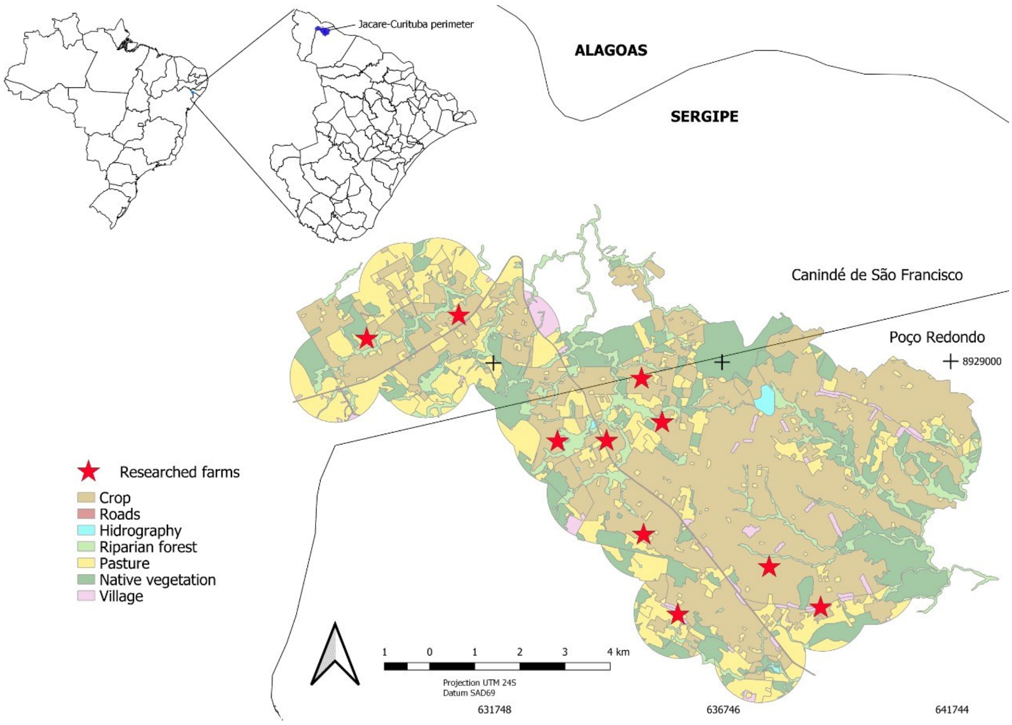

Figure 1. Map showing farms locations and land cover at the irrigated areas of Califórnia e Jacaré-Curituba, in Sergipe. Stars of different colors indicate the location of the farms and the number of low-impact agronomic practices adopted by each farmer. Font: Modified from Silva et al. (2019).

Bee sampling

According to the location and number of trees in bloom, we established a rectangular experimental area of 50 m × 25 m in size aligned along rows and placed at 10 m from the edge of the orchard or in its center, due to their small size. The dataset on bee density and richness used in this study was gathered from different sampled trees within the same experimental area following the method described by Vaissière, Freitas & Gemmill-Herren (2011).

Records were done from June to December 2017 by two collectors walking along rows and lines in opposite directions to sample flowering guava trees during good weather conditions. Each orchard was surveyed three times a day (early morning, midday, and afternoon) for two consecutive days. Flower density was counted, to guarantee the necessary number of flowers in each sampling tree, so that bee richness and abundance were recorded. We counted the number of visits to several flowers (nº bee visits/species x 100 flowers). Each collector used two hand counters, one to register the number of bee visits and another to count flowers (50 flowers in each adjacent tree). Bee density was recorded for 10 min/per tree. The total sampling effort reached four hours per orchard (six times/40 min/per sampling).

Bee species richness was recorded by collecting individuals with entomological nets swapping. For that, twelve flowering trees (six pairs of adjacent trees) were selected along the rows. Records were done for one hour, comprising five minutes of sampling in each pair of adjacent guava trees. The total sampling effort reached six hours, after six samplings per orchard survey. Insect specimens were killed in jars with ethyl acetate and transferred to Falcon tubes. Specimens were deposited at the Zoology Museum of the Federal University of Bahia (MZUFBA).

Landscape metrics

The landscapes surrounding the orchards were evaluated in terms of the proportion of remaining natural vegetation, its interpatch isolation, landscape land-cover diversity, and distance to the nearest continuous protected area. Around each sampling point, we established circular buffers with a 1 km radius within which landscape structural measures were obtained using Fragstats 4.2 (McGarigal & Romme, 2012).

As natural vegetation, we considered the sum of Native vegetation patches and Riparian forests since both play important and similar roles in providing critical nesting habitats for bees in the region. The amount of natural vegetation was measured as the proportion (PLAND) occupied by these two classes within each 1km radius buffer. Within the 1 km buffers, we also measured the mean Euclidean distance to the nearest neighbor, calculated by taking the distance between each remaining natural vegetation patch to its nearest neighboring patch and then summing all distances and dividing by the total number of patches. This index returns a reliable measure of how isolated native vegetation is in the surroundings of each farm.

Landscape diversity was calculated using the Shannon Landscape Diversity Index (SHDI), separately considering all seven mapped classes. The index returns zero when the landscape is composed of a single land-cover class and increases without limit with the availability of more and evenly distributed classes, indicating higher environmental diversity (McGarigal & Romme, 2012), which can be an important factor to foster foraging abilities and increase bee populations (Moreira, et. al., 2018).

Finally, because large continuous native vegetation areas can be important sources of migrating pollinators, helping to maintain their populations even amidst harsh environmental conditions, we also measured the distance of the sampled orchards to the nearest protected reserve (Grota do Angico Monument), the largest continuous vegetation area in the whole region. Regional land cover was mapped through a supervised classification of Landsat 8 satellite images with 30 m resolution and manually corrected using ground-truth observations and high-resolution satellite images available at the OpenLayers module of the Geographical Information System Quantum GIS 2.18 in 2018 (Figure 1).

Statistical analyses

We evaluated the effects of landscape structure on bee abundance within guava orchards using simple Generalized Linear Models (GLM). Models were made using bee and total visitors' abundance and richness as response variables, and landscape metrics as explanatory variables. Because both response variables were count data, we used the Poisson error distribution family for all models. Models were firstly checked for significance and significant models were then compared for plausibility using AIC values. All analyses were made using program R version 3.5.1.

Results

Bee survey

Nine bee species from seven genera were sampled (Table 1). From a total of 705 specimens, 92% of the individuals were collected around 6h00min, when all sampled trees had most of the flowers opened. Foraging bees were rare at 11h while just one bee was recorded at 15h.

Richness was low in all orchards surveyed, and social bees *Trigona spinipes* and *Apis mellifera* were the most abundant and frequent species (Table 1). Carpenter bees (*Xylocopa* spp.) and oil-collecting bees (*Centris* spp.) had a low number of individuals and frequency on flowers.

Table 1. List of insects visiting guava flowers collected from ten small, irrigated farms in semiarid Caatinga, in Sergipe State, Brazil. Font: Calazans et al. (2022).

Family	**Species**	**Number**
Apidae	*Apis mellifera scutellata* (Lepeletier, 1836)	377
	Trigona spinipes (Fabricius, 1793)	296
	Centris (*Centris*) *aenea* (Lepeletier, 1841)	2
	Centris (*Trachina*) *fuscata* (Lepeletier, 1841)	1
	Exomalopsis (*Exomalopsis*) *analis* (Spinola, 1853)	3
	Xylocopa (*Neoxylocopa*) *frontali* (Olivier, 1789)	9
	Xylocopa (*Neoxylocopa*) *grisescens* (Lepeletier, 1841)	4
	Augochloropsis sp1	2
Halictidae	*Dialictus opacus* (Moure, 1940)	11
Total		**705**

Landscape

Model selection identified no significant relation between bee richness and landscape metrics ($p<0.05$). However, bee richness was low in all orchards surveyed, and data were insufficient to be analyzed. Regarding bee abundance, we did not find any direct influence on the proportion of the surrounding landscape covered by natural vegetation ($p=0.326$). Conversely, we found significant effects on bee abundance for the other surrounding landscape factors. Increased landscape diversity (as measured through SHDI) led to a lower abundance of bees (estimate = -0.58; std.error = 0.08; $p<0.001$; AIC = 807.59), but with great variation among sampled points, especially for the most diverse landscapes (Figure 2A), which presented from about 100 up to 400 bees per orchard at the same SHDI values.

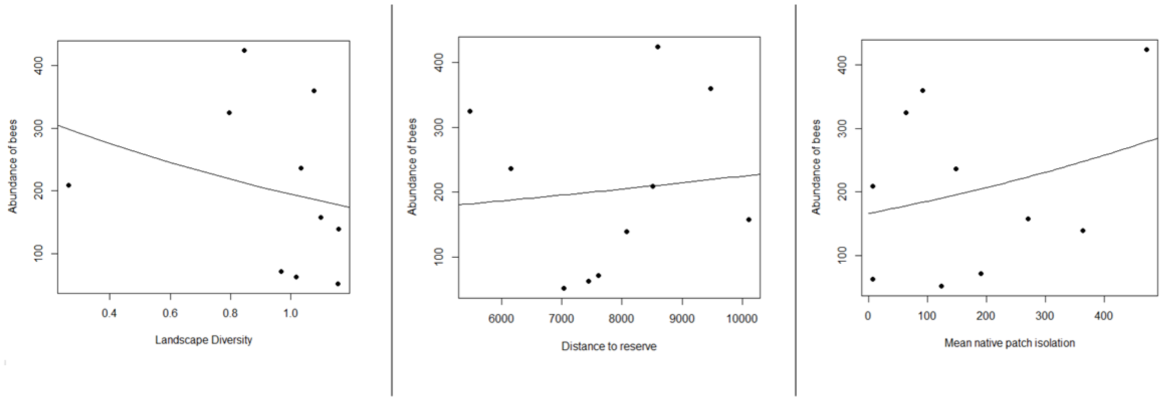

Figure 2. Variation in the abundance of bees from ten guava orchards about the surrounding landscape factors: A. landscape diversity (SHDI); B. distance to the Grota do Angico Monument reserve; C. native vegetation patches isolation. Font: Calazans et al. (2022).

On the other hand, we found higher abundances of bees as natural vegetation patches became more isolated between each other (estimate = 0.001; std.error = 0.0001; $p<0.001$; AIC = 803.59) (Figure 2C), and orchards were more distant from the nearest largest continuous Caatinga protected area habitat represented by the Grota do Angico Monument reserve area (estimate = 0.0005; std.error = 0.00004; $p = 0.005$; AIC = 851.51) (Figure 2B). When compared, AIC values show the native vegetation isolation model to be the most plausible explanation, even though the other variables also confer some information on the effects of landscape structure on pollinators.

Discussion

The bee fauna associated with Guava orchards in semiarid Sergipe differentiates from other surveys regarding the low number of species, especially of native solitary bees, and the absence of Meliponini bees, except for *Trigona spinipes* which was also found in nearby fragments surveyed with pan traps (Calazans, 2019). Meanwhile the dominance of the social Africanized honeybee *Apis mellifera*) and native *T. spinipes*, is a common finding in all surveys for this crop in Brazil, both in semiarid Caatinga (Alves & Freitas, 2007; Castro, 2002; Siqueira et al., 2012) and from other regions (Guimarães, Pérez-Maluf & Castellani, 2009). These bee species are common winners in conventional agricultural context since they build aerial nests and are generalists in both habitat and feeding requirements (Kleinert & Giannini, 2012), while native social bees are losers since they rely on preexisting cavities in the trunk and branches of trees and ground to build their nests (Nogueira-Neto, 1997). Concerning solitary bees, *Dialictus* sp., *Melitoma segmentaria*, *Melissodes* sp., *Augochloropsis* sp., *Psaenythia* sp., *Ancyloscelis apiformis*, *Melitomella grisescens*, occurs in nearby fragments but not within Guava crop (Calazans, 2019). Since this is the first record of bees associated with Guava, a further survey is needed to understand the effect of within-crop habitat and management on bee richness and abundance.

Guava flowers open during the early morning and pollen is the only resource for pollen feeders, comprising an interval previously recorded for the species (Alves & Freitas 2007; Hedström, 1988). The availability of pollen is one factor explaining that all species were collected before 11 a.m. Additionally, the highest density of visits was recorded during the early morning, suggesting that most of the pollen will be depleted by the end of the day (Castro 2002; Siqueira et al., 2012). According to previous studies on flower biology of this crop variety, stigma is receptive to anthesis and intense bee foraging activity, when there is the greatest number of blooming flowers (Siqueira et al., 2012). Consequently, pollination is about to happen mainly during the morning, although flowers remain open all day (Hedström, 1988, Siqueira et al., 2012, Klein et al., 2020). In such a context, pollen from guava flowers is an important source of protein for the brood, but adult insects still need nectar for energy uptake. Since Guava flowers are nectar-less, bees tend to search for other plant species in other crops or nearby natural and semi-natural habitats (Klein et al., 2007).

Although Africanized honeybees can perform pollination in Guava, it is widely accepted that relying on a single pollinator species is risky and does not substitute other native bees (Garibaldi et al., 2013; Giannini et al., 2015; BPBES/REBIPP, 2019). Pollination provided by Africanized honeybees can be improved by native bees (Alves & Freitas, 2007; Freitas & Alves 2008; Guimarães, Pérez-Maluf & Castellani, 2009; Siqueira et al., 2012; Viana et al., 2014), such as

Melipona quadrifasciata anthidioides (Mandacaia) (Slaa et al., 2006), which was not found in our studied farms, and solitary *Xylocopa* spp. (carpenter bees) (Siqueira et al., 2012). In addition to guava, at least six crops within farmlands are partially (ex. Okra, bean) or dependent on pollinating bees (ex. acerola, papaya) and would benefit from a local increase in bee communities' abundance and diversity (Silva et al., 2019).

Support for meliponiculture within farmlands would also improve local social native bee populations, such as Mandacaia, only to mention one. Despite the potential use of beehives for pollination (both Africanized honeybees and social native bees), no farmers adopt such practices (Silva et al., 2019). Although conserving and restoring Caatinga habitats within agricultural settlements is preconized in the Brazilian Environmental Law, it remains a challenge because of the cultural use of wood and the spread of irrigated land in semiarid domains (Leal et. al., 2003). According to Brazilian Environmental Law, small landowners have no legal obligation to keep native areas within their farms. The settlement must keep native vegetation along water streams within it, but continuous native vegetation should also be placed on the edge of crops and between crops and farms.

A bunch of evidence gathered from agroecosystems worldwide reveals that these habitats select for generalized bee groups, while native bees tend to be excluded or reduced (BPBES/REBIPP, 2019), which threatens pollinators and pollination services for crop production (Garibaldi et al., 2013). Despite the potential importance of pollinators to increase the production of Guava and some other local crops, the value of the native bees as pollination providers (Giannini et al., 2015) is still being overlooked locally.

Due to the fragmentation and degradation of near- and semi-natural habitats, habitat loss is probably detrimental to these bees in the study site (Kleinert & Giannini, 2012). In semiarid Caatinga deforestation and selective logging (Felix & Freitas, 2021) are pointed to as important drivers of bee population decline in semiarid regions (Viana et al., 2014). In our study, a possible explanation for the negative effect of landscape diversity on bee abundance relates to the low quality of habitats, mainly composed of annual crops and pastures for livestock. This is especially important during the dry season, when Caatinga vegetation faces drought, lowering food resources and forming a barrier to the movement of native bees (Viana, 2008). The fact that the abundance was higher in the Guava crop when Caatinga was far from patches and farther from the largest area of continuous Caatinga vegetation, suggests a crowding effect since Africanized honeybees and *T. spinipes* can use crop habitat for feeding and nesting. On the other hand, native social bees tend to nest nearby the previous one, since they do not have swarm behavior, are small, short-flight range foragers, and are sensitive to high temperatures (Nogueira-Neto, 1997). Further investigation is recommended to access habitat quality since this study highlighted the importance of surrounding habitat patches for native bees in semiarid Sergipe.

Conclusion

This study presents the first record on bee fauna associated with crops in settlements in semiarid Sergipe, so providing helpful information to further studies aiming to address the potential impact of pollinator loss.

Model selection identified no significant relation between bee richness and landscape metrics. Although, we found higher abundances of bees as natural vegetation patches became more isolated. Thus, providing nesting sites, floral resources, and habitat connectivity, are recommendations for landscape management fitting all crops in the production area. Together with educational and participatory actions as tools, economic support such as payment for environmental services or other monetary incentives should be discussed to drive a change regarding the attitude of the producers towards ecosystem services conservation.

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