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CROP PROTECTION

Diversity and abundance of bees in *Passiflora edulis* Sims (Passifloraceae) orchard, associated with *Solanum lycocarpum* St. Hill. (Solanaceae)

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ABSTRACT. Brazil is the third-largest producer of fruits in the world, with yellow passion fruit (*Passiflora edulis*) as one of its main crops. This species requires cross-pollination, with *Xylocopa* bees being the primary pollinators due to its self-incompatibility. The presence of *Solanum lycocarpum* close to passion fruit orchards can serve, due their flowers, as an attraction for pollinating bees, improving the production of the crop. Thus, the objectives of this study were to: i) investigate whether the planting of *S. lycocarpum* close to the passion fruit orchard increased the richness and abundance of bees; ii) evaluate whether the implementation of trap nests in the passion fruit orchard and close to *S. lycocarpum* attracted bees to nests in this location; iii) record the time of greatest foraging activity of *Xylocopa frontalis* in the passion fruit orchard; and iv) quantify the number of natural nests of *X. frontalis* in the passion fruit orchard during the experimental period. A total of 48 seedlings of *S. lycocarpum* were planted and divided into two rows along the eastern border of the yellow passion fruit crop. Bees were recorded for 15 minutes each hour from 8:30 am to 3:30 pm. During the remaining 45 minutes, the posts were inspected for natural bee nests. The frequency, abundance, species richness, and indices of Shannon-Winner, Simpson, and Pielou equitability indices were assessed. The most common species were *X. frontalis*, *Apis mellifera*, and *Trigona spinipes*. The flowering of *S. lycocarpum* near passion fruit orchards positively influenced the increase in the number of nests and species richness of pollinating bees, indicating that this plant, close to passion fruit orchards, can contribute to fruit production. Finally, we showed the preferred times for bee foraging and the period in which insecticide application should be avoided.

Keywords: fruit growing; pollination; trap nests; yellow passion fruit.

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Introduction

The family Passifloraceae comprises 18 genera approximately 630 species, approximately 400 of which are widely distributed in tropical regions (Casierra-Posada & Jarma-Orozco, 2016). Brazil has a rich diversity of Passifloraceae, with approximately 135 species producing edible fruits (Silva, Oliveira, & Garófalo, 2014). Worldwide, *Passiflora edulis* Sims (yellow passion fruit) is the most cultivated, followed by *Passiflora alata* (sweet passion fruit) and *Passiflora quadrangularis* (Malpighiale: Passifloraceae) (Silva et al., 2014).

Brazilian commercial plantations most commonly use two species, *P. alata* (sweet passion fruit) and *P. edulis* (sour passion fruit or yellow passion fruit), which represent 95% of the crops (Silva et al., 2014). Yellow passion fruit is cultivated in several Brazilian states, making Brazil the world's largest fruit producer (Vidal et al., 2023).

P. edulis is a tropical climbing plant that flowers year-round when cultivated under favorable conditions of temperature and humidity. Its flowers are large, have characteristic smells, and have both female and male structures called hermaphrodites. It contains a large amount of nectar that attracts insects. In general, flowers open at approximately 11:00 am and remain open until 6:00 pm. If fertilization does not occur, they fall (Silveira et al., 2012; Silva et al., 2014).

Solanum lycocarpum St. Hill (Solanales: Solanaceae), popularly known in Brazil as lobeira (Silva Júnior, 2005), blooms practically throughout the year, which favors the foraging activity of bees (Tavares, Alves, Morais, Polatto, & Dutra, 2018). This plant can grow and develop under unfavorable environmental conditions, such as acidic and nutrient-poor lands, and can withstand arid climates and prolonged periods of drought (Feliciano & Salimena, 2011). According to Almeida et al. (2022), *S. lycocarpum* is an important food source for both vertebrates and invertebrates. In addition, it will assist in the conservation of native bee populations. Thus, its conservation is necessary, not in isolation, but in a planned and integrated manner aimed at the conservation of the biome in which the species is part (Silva, Aleixo, Nunes-Silva, Freitas, & Imperatriz-Fonseca, 2010).

One aspect that makes passion fruit self-fertilization difficult is the fact that the flower presents a phenomenon known as protandry, that is, the pollen matures before the stigma of the same flower. These characteristics render passion fruit production dependent on pollinating bees (Junqueira & Augusto, 2017).

Bees in the family Apidae are considered to have the greatest diversity (Orr et al., 2022). In Brazil, there is a great diversity of bees distributed among meliponine species, as well as social and solitary bees. They are the main pollinators of many plant species in both natural and cultivated ecosystems (Silveira, Melo, & Almeida, 2002).

Bees are considered the most important pollinators because of their population index, visitation, and floral fidelity. The greater the frequency of visitation by a bee on a flower, the more frequent the visitation and the greater the chances of the visited flowers being pollinated (Ogilvie & Thomson, 2016).

The implementation of trap nests has contributed to an increase in *Xylocopa* Latreille (Hymenoptera: Apidae) bees. These nests are similar to *Apis mellifera* L. (Hymenoptera: Apidae) hives and receive adjustments that meet the nesting needs of *Xylocopa* (Da Silva & Freitas, 2018). The planting of passion fruit in combination with *S. lycocarpum* plants can favor nesting, attraction, and keeping bees close to the plantation. In addition, this consortium can increase the diversity and population of pollinating bees, promoting an increase in productivity and a decrease in production costs, as *S. lycocarpum* attracts floral visitors and passion fruit pollinators (Silva et al., 2014).

The objectives of this study were to: i) evaluate whether the planting of *S. lycocarpum* close to the passion fruit plantation increased the richness and abundance of bees; ii) assess whether the implementation of trap nests in the passion fruit plantation and close to *S. lycocarpum* attracted bees to nests in this location; iii) record the time of greatest foraging activity of *X. frontalis* in the passion fruit plantation; and iv) quantify the number of natural nests of *X. frontalis* in the passion fruit plantation during the experimental period.

Material and methods

Location and characterization of the sample area

The study was carried out in the Itamarati settlement (22°12'19.3" S; 55°34'37.3" W), located 45 km from the municipality of Ponta Porã, state of Mato Grosso do Sul, Brazil, and 21 km from the border with Paraguay, in the Center-West region of Brazil. The climate of the municipality of Ponta Porã, according to the criteria of Köppen (1948), is *Cwa*, that is, subtropical climate, with dry winter (temperatures below 18°C) and hot summer (temperatures above 22°C). Ponta Porã exhibits a short dry season (1-2 months) that covers the months of July to August, where the average rainfall is less than 50 mm. The annual water deficit is practically zero and the water surplus is approximately 670 mm, considering that the available water capacity (AWC) is 100 mm (Lorençone, Aparecido, Lorençone, Lima, & Torsoni, 2022). The annual average temperature is 21.0°C and the rainfall is 1,674 mm (CEMETEC, 2018). The soil is of the dystroferric Red Latosol type (Garbiate, Vitorino, Mauad, & Bergamin, 2014).

The experimental area was one hectare, with pastures located close to the west, east, and south. There was a small sugarcane (Poales: Poaceae) crop to the north and south of the passionfruit orchard, which served as a living fence. In the north, there is a secondary road with little car traffic.

Passion fruit orchard

The research was conducted in a passion fruit orchard in an organic production system implemented in August 2013. It was a commercial crop, with all production destined for a juice processing company, located in Campo Grande, Mato Grosso do Sul State, Brazil (Bio Frutas Orgânicos). This orchard had 600 passionfruit plants distributed in 20 columns, with 30 plants in each column and a spacing of 3 m. The distance between the passion fruit plants was of 2.5 m. The conduction system was a vertical espalier with a wire and stakes, and an untreated eucalyptus post 2.5 m high.

The experimental area was demarcated into six quadrants, each consisting of 20 columns, each containing five passion fruit plants, such that each quadrant contained 100 plants.

Planting of *Solanum lycocarpum*, recording and implementation of trap nests, and sampling

In each of the 100 tubes (1.4 x 12 cm in height), a seed of *S. lycocarpum* was sown, one centimeter deep, kept in open air, and irrigated three times a day on the campus of the *Universidade Federal da Grande Dourados* (UFGD). At 126 days after germination, the plants were approximately 15 cm in height and were transferred individually to 4-liter plastic pots containing sand, earth, and substrate in a 1:1:1 ratio. After 60 days, the plants were vigorous, and their roots were fully expanded.

In August 2015, *S. lycocarpum* plants were approximately 50 cm in height and were taken from the UFGD to the Itamarati settlement, where they were planted under field conditions. Two lobeira plants were planted in each row (column) of passion fruit plants, totaling 40 plants per quadrant, with the same spacing as described for the passion fruit orchard. The first flowering of *S. lycocarpum* occurred 90 d after planting in the field.

This study was conducted over two consecutive years, from August 2015 to June 2016, totaling 18 collections, which were carried out fortnightly from 8:30 am to 5:45 pm. Assessments were performed for 15 minutes each hour. Samples and records of the bees were collected by two researchers who walked randomly through a passionfruit orchard. The bees were registered through photos and filming, and eventually captured with the aid of an entomological net and taken to UFGD for identification purposes.

According to the methodology of Pereira and Garófalo (2010), two supports were used for trap nests in the northern and southern regions of the passion fruit orchards. There were two shelves in each support, which served as a base for a total of 20 bricks of the "Baiano type," which accommodated the bamboos (trap nests) in their holes. Each bamboo was cut at the internode, leaving only one side open, with lengths between 15.0 and 30.0 cm and from 2.0 to 2.5 cm diameter. The bamboos were inspected every 15 days to assess the existence of bee nests and local cleanliness.

At each collection interval, existing natural nests on the passion fruit orchard posts were recorded. The nest was considered active when the existing holes in the posts were clean or when they contained fragments of bee excrement.

Vigor evaluation of passion fruit plants by quadrant

In October 2015, at the beginning of the study, the passion fruit orchard was evaluated according to the vigor of the plants per quadrant, with scores ranging from 01 to 05. The evaluations were performed by two researchers who, through visual observation, attributed scores to plants within the quadrant.

The parameters used to evaluate the vigor of the passion fruit orchards in the quadrants were leaf color and size, number of leaves per plant, number of flower buds and flowers per plant, and number of plants per quadrant.

The scores assigned to the quadrants containing the passion fruit plants were: 1 = quadrant with planting failure (absence of ⩾ 30% of plants); plants with few leaves (wrinkled, poorly developed leaf), and few flowers; 2 = quadrant with 15% of planting failure; plants with many leaves, but few vigorous and the presence of some flowers; 3 = quadrant without planting failure, with many vigorous leaves and 60% flowering; 4 = quadrant without planting failure, with vigorous leaves and approximately 70% of plants presenting flowers; and 5 = quadrant without planting failure, and with vigorous leaves and practically 100% flower production.

Ecological Analysis

For data organization and evaluation, the frequency and constancy parameters described in Silveira Neto, Nakano, Barbim, and Villa Nova (1976) were used, where frequency (f) is the percentage of individuals of a species in relation to the total number of individuals. Constancy (C) is the percentage of species present in the surveys, $C = (P \times 100)/N$, where P corresponds to the number of collections containing the species and N to the total number of collections performed. When the species was present in more than 50% of the samples, it was considered constant (w); if it appears in 25-50% of the samples, it was considered accessory (y); and if present in less than 25%, it was considered accidental (z).

To determine dominance (d), it was used the criterion described in Uramoto, Walder, and Zucchi (2005), in which a species is considered dominant when its frequency is greater than 1/S, where S is the total number of species in the community. The absolute abundance (n) was determined by counting the number of individuals registered and captured at the respective sites.

The Shannon-Wiener, Simpson, and Pielou equitability indices were determined according to Krebs (1978), Ludwig and Reynolds (1988), and Maguran (1988). Simpson's index (D) expresses the probability that two individuals from a sample, chosen at random, belong to the same species, and was calculated by the relation $D = \sum pi^2$, in which pi is the proportion (ni/N) of each species i divided by the total number of individuals in the sample.

The Shannon-Wiener index (H') measures the degree of uncertainty in determining to which species an individual chosen at random will belong, from a sample with S species and N individuals. The lower the value, the lower is the degree of uncertainty, denoting low diversity. This index is determined by the expression ($H' = -\sum (pi. \ln pi)$). The Pielou Equity Index (J') measures the proportion of diversity as the maximum diversity ($J' = H'/H'max$), where Hmax = ln(S). The value of J' varies between zero and one, where one represents a situation in which all species are equally abundant.

Results

Faunistic analysis of bees in a passion fruit orchard

At the start of the evaluation, the passion fruit plants were entering their third production. Flower buds began to form, but no flowers had yet opened. Furthermore, *S. lycocarpum* was not in full bloom and had only two flowering plants.

Of the 701 bees recorded in the sample area during the eight months of evaluation, the species found in greater numbers were *X. frontalis*, (242 specimens), *A. mellifera* with 319 specimens, and *T. spinipes* with 125 specimens.

During the sampling period, the smallest number of bees was recorded in October, when only five bees were recorded in the second sampling period. *X. frontalis* was the most frequent species was *X. frontalis*, with a higher frequency in November and December, followed by *A. mellifera*. *T. spinipes* bees were recorded only from February onwards and were more frequent in April (Figure 1).

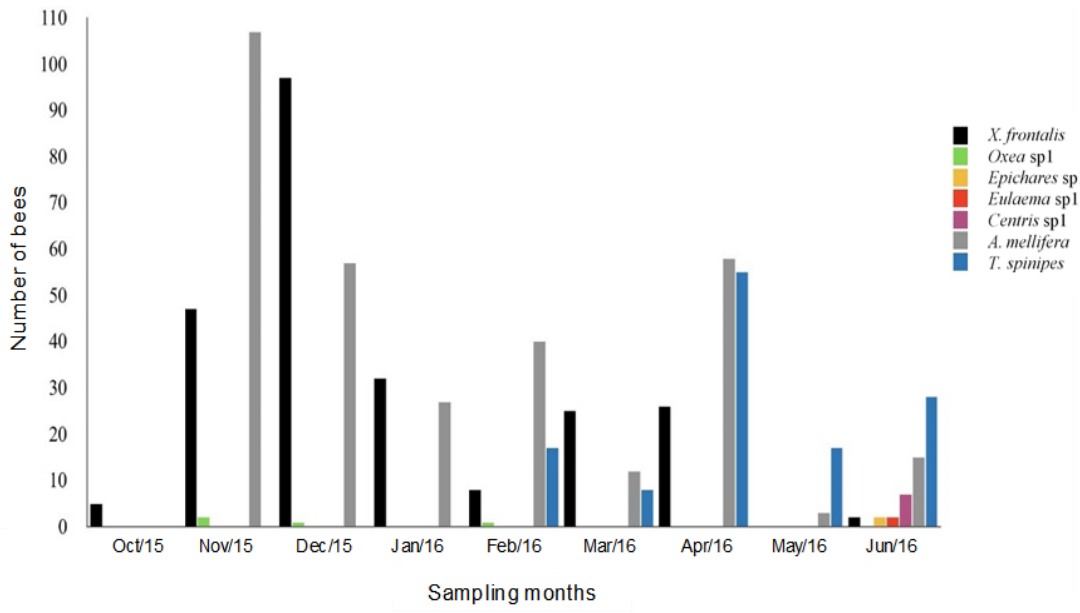

Figure 1. Diversity of bees in a *Passiflora edulis* orchard, from October to December 2015, and from January to June 2016, in Itamarati, Ponta Porã, Mato Grosso do Sul State, Brazil.

During the sampling period, seven Apidae species were recorded (Table 1). Small bees were considered those with 0.5 to 1.0 cm length, and large bees those with 1.8 to 2.6 cm length and 0.7 cm height (Benevides et al., 2009). The species *Apis mellifera*, *Xylocopa frontalis*, and *Trigona spinipes* were considered dominant and constant. In contrast, *Oxea* sp.1, *Epichares* sp.1, *Eulaema* sp.1, and *Centris* sp.1 were classified as accidental. Simpson (D) and Shannon-Winer (H') indices indicated high diversity, confirmed by the high Pielou Equitability (J') index (Table 1).

Table 1. Dominance and constancy of bee species in a passion fruit orchard, in the Itamarati settlement, Ponta Porã, Mato Grosso do Sul State, Brazil, from October 2015 to June 2016.

Apidae	N	Frequency (%)	Dominance	Constancy
Large bees				
Xylocopa frontalis	242	34.52	d	77.8 (w)
Oxea sp.1	4	0.571	n	16.7(z)
Epichares sp.1	2	0.285	n	5.56 (z)
Eulaema sp.1	2	0.285	n	5.56 (z)
Centris sp.1	7	0.999	n	5.56 (z)
Small bees				
Apis mellifera	319	45.51	d	61.1 (w)
Trigona spinipes	125	17.83	d	44.6 (w)
Total	701			
Riqueza (S)	7			
H'	1.14			
D'	0.36			
J"	0.59			

N = number of individuals of each species sampled in the passion fruit orchard; frequency (%) = percentage relative to the number of individuals of each species sampled in the passion fruit orchard; d = dominant species, n = non-dominant species; C = constancy of each species found in the samples: (w) = constant and (z) = accidental; S = species richness; H'= Shannon-Wiener index; D' = Simpson index; J' = Pielou index.

Number of bees by time of day

The highest bee activity was recorded between 12:30 and 4:30 pm. At 12:30, the bees with the highest number of records were *X. frontalis* (33 visits to flowers) and *A. mellifera* (28 visits). At 1:30 pm, the most frequent bees were *A. mellifera*, with 115 records; *X. frontalis*, with 45 individuals observed; and *T. spinipes*, with 42 records; a greater richness of bee species was found. At 2:30 and 3:30 pm, in addition to *X. frontalis*, *A. mellifera*, and *T. spinipes*, the following species were recorded: *Oxea* sp.1 and *Epichares* sp.1. Therefore, the highest richness and second-highest abundance of bees were observed during this period. The hours with the lowest numbers of *X. frontalis*, *A. mellifera*, and *T. spinipes* were in the early morning, with 14 bees, and in the late afternoon, with 17 bees. At the beginning of collection (sampling), between 8:30 am and 9:30 am, greater richness and lower abundance were observed (Table 2).

Table 2. Apidae species recorded at different time intervals, in a *Passiflora edulis* orchard, in the Itamarati settlement, Ponta Porã, Mato Grosso do Sul State, Brazil, from October 2015 to June 2016.

Bee species	8:30 8:45 am	9:30 9:45 am	10:30 10:45 am	11:30 11:45 am	12:30 12:45 pm
Xylocopa frontalis	4	17	25	31	33
Oxea sp.1	0	1	0	0	1
Epichares sp.1	0	0	0	0	0
Eulaema sp.1	1	0	0	0	0
Centris sp.1	2	4	0	0	0
Apis mellifera	6	8	2	2	28
Trigona spinipes	1	5	20	4	8
Total	14	35	47	37	70
S	5	5	3	3	4
Bee species	**1:30 1:45 pm**	**2:30 2:45 pm**	**3:30 3:45 pm**	**4:30 4:45 pm**	**5:30 5:45 pm**
Xylocopa frontalis	45	24	30	25	8
Oxea sp.1	0	1	1	0	0
Epichares sp.1	0	1	1	0	0
Eulaema sp.1	1	0	0	0	0
Centris sp.1	0	0	0	1	0
Apis mellifera	115	69	67	17	5
Trigona spinipes	42	21	10	10	4
Total	203	116	109	53	17
S	4	5	5	4	3

S = species richness.

Effect of *Solanum lycocarpum* on bee attraction

The evaluations of bee species diversity by quadrant indicated that quadrants III and IV (intermediate) had greater diversity; quadrant III showed H' = 1.15 and D' = 0.37, while quadrant IV displayed H' = 1.11 and D' =

0.37. The results obtained in quadrants V (with H' = 0.75 and D' = 0.59) and VI (H' = 0.74 and D' = 0.54) indicated that in these quadrants, more distant from *S. lycocarpum*, the lowest diversity of floral visiting agents was found (Table 3).

Table 3. Diversity of bee species in a *Passiflora edulis* orchard, in different sample quadrants (I-VI), in the Itamarati settlement, Ponta Porã, Mato Grosso do Sul State, Brazil.

Bee species	I	II	III	IV	V	VI	Total
Xylocopa frontalis	41	57	84	54	4	2	242
Oxea sp1	0	0	2	2	0	0	4
Epichares sp.1	0	0	1	1	0	0	2
Eualema sp.1	0	1	1	0	0	0	2
Centris sp.1	0	2	5	0	0	0	7
Apis mellifera	9	70	110	68	26	36	319
Trigona spinipes	36	17	29	23	5	15	125
Total	86	148	231	148	35	53	701
S	3	5	7	5	3	3	7
H'	0.95	1.06	1.15	1.11	0.75	0.74	1.14
D’	0.41	0.39	0.37	0.37	0.59	0.54	0.36
J'	0.87	0.66	0.59	0.69	0.68	0.68	0.59

I = Quadrant 1, II = Quadrant 2, III = Quadrant 3, IV = Quadrant 4, V = Quadrant 5, VI = Quadrant 6; S = Species richness, H'= Shannon-Wiener index, D' = Simpson index; J'= Pielou's Equity Index.

Vigor evaluation of *Passiflora edulis* plants

The results of the vigor evaluation of *P. edulis* plants revealed that the first quadrant (closest to *S. lycocarpum*) had the lowest vigor, with a score of one. The second quadrant had few planting failures; however, the leaves were not vigorous, and flower production was approximately 50%, thus assigning a score of 2 to this quadrant. In the third quadrant, the plant characteristics changed considerably. These plants had healthy leaves (bright green) and high flower production; the highest score was assigned to this quadrant (five). This note was assigned to the fourth quadrant. In the next quadrant (V), flower production declined with a score of four. Floral falls extended to the sixth quadrant with a score of three.

Influence of temperature and rainfall on bee population dynamics

Of the total of 18 samplings carried out in the *P. edulis* orchard, the lowest incidence of bees occurred on days when rainfall and low temperatures were recorded, that is, in the second and fifteenth samplings. Concerning the rainfall and temperature recorded during the research period, the day with the highest amount of rain (44.80 mm) was in the second sampling, where the minimum temperature was 17.5°C and the maximum 23°C. In the fifteenth sampling, a high incidence of rain (18.85 mm) was also recorded, with a minimum temperature of 13.10°C and a maximum of 24.60°C. Therefore, the number of bees was low on these two sampling days (Figure 2).

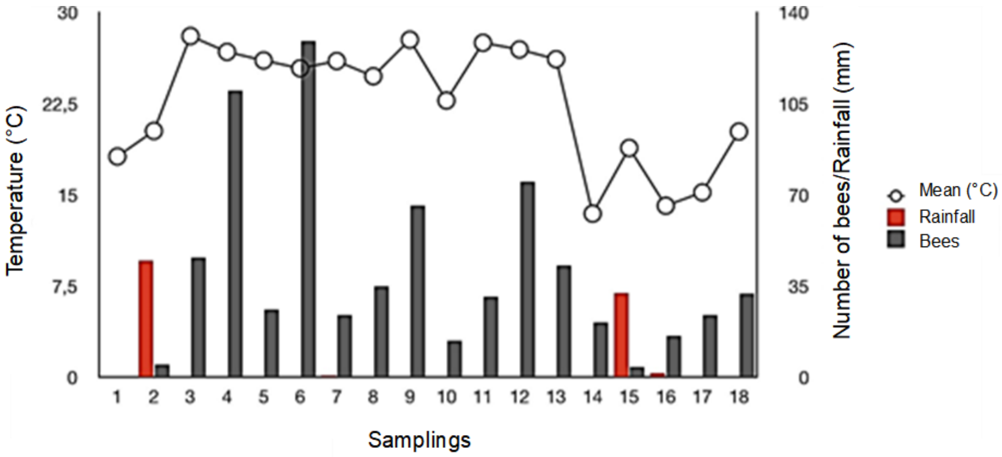

Figure 2. Bee richness in a *Passiflora edulis* orchard in Itamarati, Ponta Porã, Mato Grosso do Sul State, Brazil, temperature and rainfall indices. Climatological data: Climate, Weather, and Water Resources Monitoring Center of Mato Grosso do Sul. Meteorological Station A-703, Ponta Porã, Mato Grosso do Sul State, Brazil. October 2015 to June 2016. (https://www.cemtec.ms.gov.br/ Accessed: June 25, 2023).

Bee nesting survey

From October 2015 to June 2016, 269 *X. frontalis* nests were recorded, found on the posts of the *P. edulis* orchard and eventually on the support of trap nests. The smallest number of nests occurred in the first and second samplings, with four nests each, and the largest number occurred in the fourteenth and fifteenth samplings, with 20 nests each. No nesting was recorded on the bamboo fragments used as trap nests. However, the bees nested naturally in the wood of the structure that supported the bamboo and posts of the passion fruit orchards.

During the sampling period, 701 bees and 269 nests of *X. frontalis* were found. The number of bees in the orchard varied, peaking at the fourth and sixth collections. The number of nests increased up to the eighth sampling; thereafter, a linear record was maintained between 17 and 20 nests (Figure 3).

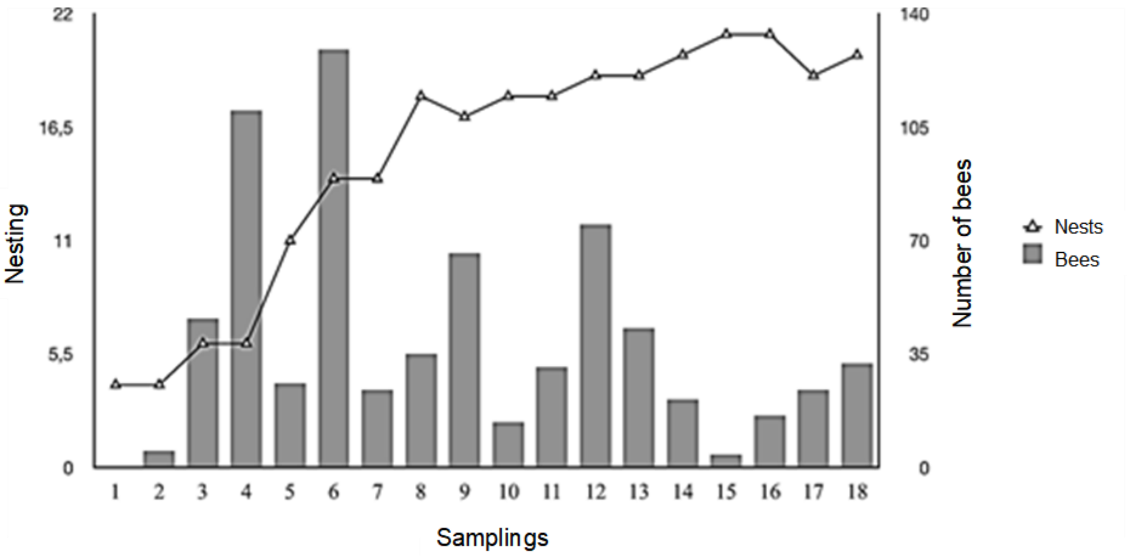

Figure 3. Richness of bees and number of nests found in a *Passiflora edulis* orchard in the Itamarati settlement, Ponta Porã, Mato Grosso do Sul State, Brazil, from October 2015 to June 2016.

Discussion

There were no records of *Xylocopa* during the first field sampling. This absence may be related to the lack of floral resources, as the passion fruit orchard started to bloom with only flower buds and the *S. lycocarpum* plants were not in full bloom. According to Silva et al. (2014), studies on methods for surveying and conserving bees indicate that for the maintenance of *Xylocopa* bees, it is necessary to understand their biology and the ecological resources used in feeding adults and immature bees, and that it is difficult to find bees of this genus in passion fruit orchards in degraded surroundings. According to Benevides, Gaglianone, and Hoffmann (2009), the fragmentation of natural habitats of passion fruit pollinating bees, through the expansion of agricultural and livestock areas are the main causes of the reduction in the diversity and abundance of *Xylocopa*.

In the second sampling, the number of bees was low compared to that in the following samplings, with a similar result in the fifteenth sampling, with a low incidence of bees (Figure 3). This may be associated with temporal factors such as excessive rainfall and temperatures below 20°C. These results are similar to those of Marchi and Melo (2010), who observed reduced foraging activity of *X. frontalis* on colder days during their study on this species' nesting biology. However, Farias-Silva and Freitas (2021) stated that the efficient endothermy of *Xylocopa*, especially in the early hours of the morning, combined with the large body mass of these bees allowed them to forage under conditions that would be impossible for smaller bees, especially at low temperatures. Sousa and Meletti (1997) claimed that the frequency and intensity of rainfall, associated with a low incidence of radiation, contribute to lower floral production in passion fruit cultivation, reducing the visitation of pollinating bees.

Starting from the third sampling, the floral characteristics of the passion fruit orchard and *S. lycocarpum* changed, leading to more frequent observations of *X. frontalis* and *A. mellifera*. However, the greater the number of *A. mellifera* observed on passion flowers, the lower the number of *X. frontalis*. The presence of *A. mellifera* in the flowers displaced *X. frontalis* bees, which then moved to other flowers or migrated to flowers of *S. lycocarpum* plants. This same behavior of *A. mellifera* was observed by Cobra, Silva, Correia Dias, Karburg, and Fernandes Miranda (2015), who studied the floral and pollinator characteristics of passion fruit. Bresnahan et al. (2023) also reported the aggressive behavior of *A. mellifera*.

Although *A. mellifera* is beneficial to most crops, in Passifloracea, it tends to inhibit the visitation of the main pollinators, such as *X. frontalis*. Some authors have negatively correlated the presence of *A. mellifera* in passion fruit orchards, as these bees reduce the availability of pollen grains in passion fruit flowers, and consequently reduce the visitation of large bees (Silva et al., 2014; Cobra et al., 2015).

T. spinipes was recorded for the first time in February, with a population peak in April, similar to *A. mellifera*. However, in this same month *X. frontalis* was not found. The fact that *X. frontalis* was not registered in April may be related to the low availability of floral resources in passion fruit orchards owing to the activity of *A. mellifera*. The absence of *X. frontalis* may also have occurred because of the behavior of *T. spinipes*, which, when perforating the nectariferous chambers, causes a decrease in floral resources, making the flowers unattractive to *Xylocopa*, in addition to causing premature flower fall, making it unfeasible for floral visitation by *Xylocopa* (Silva et al., 2014).

The highest activity of *T. spinipes* was observed at 10:30 am. This result differs from Cobra et al. (2015), who, when studying the floral and pollinator characteristics of sour passion fruit, found greater activity of the species *T. chanchamayoensis* and *T. hyalinata* between 2:30 pm and 4:30 pm. This indicates that different species may prefer foraging at different times of day. *X. frontalis* foraged for passion fruit flowers between 10:30 am and 4:30 pm. The highest activity occurred at 1:30 pm, indicating that these bees prefer floral visits during the hottest hours of the day. According to Benevides et al. (2009), peak nectar production in *P. edulis* flowers occurs between 12:30 and 14:30h, attracting a greater number of visitors and pollinators. These results are in accordance with those of Cobra, Silva, and Krause (2017), who claimed that the highest nectar production occurred at 2:30 pm and decreased gradually at later evaluation times for all evaluated cultivars.

In addition to *Xylocopa*, other large bee species visited (less frequently) passion fruit flowers, such as *Oxea* sp., *Epichare* sp., *Eulaema* sp., and *Centris* sp. It is worth noticing that these four genus contain species considered accidental. In studies conducted by Benevides et al. (2009), these genera were found in low numbers.

The low occurrence of *Oxea* sp.1, *Epichares* sp.1, *Eulaema* sp.1, and *Centris* sp. may be related to the fact that the areas surrounding the passion fruit orchard are intended for pasture, with a lack of floral resources, mainly for Centridini, which are oil-collecting bees. In addition, this group needs specific areas for nesting, such as the presence of termite mounds (Moure-Oliveira, Rocha-Filho, Ferreira-Caliman, & Garófalo, 2017), which does not occur near the study area. According to Pereira and Garófalo (2010), it is important for passion fruit-pollinating bees to have sources of food resources close to the cultivated areas, mainly to meet their need for foraging when the cultivar has low flowering.

Among the evaluated quadrants, the second, third, and fourth quadrants had the highest bee abundance and richness. Furthermore, the Shannon and Simpson indices indicated greater species diversity in these quadrants. These results can be explained by the fact that in these quadrants, passion fruit plants were more vigorous, with a greater number of flowers, combined with the proximity of *S. lycocarpum* plants to attract pollinating bees. The availability of food resources around cultivated areas directly influences the richness of pollinating bees, favoring crop production (Silva et al., 2014).

The low abundance of bees in the last two quadrants may be related to their distance from *S. lycocarpum*, as the flowers of these plants are strongly attracted to bees. The presence of *S. lycocarpum* near passion fruit orchards can help keep large bees, such as *Xylocopa,* closer to the orchard (Silva et al., 2014).

Of the seven bee species observed in the sampling area during the evaluation period, *A. mellifera*, *X. frontalis*, and *T. spinipes* were the dominant species in all samples. The constant presence of *A. mellifera* is related to its generalist behavior (Gillespie & Elle, 2018). Therefore, these bees make passion fruit orchards suitable foraging places. *T. spinipes* bees are common in this region, although there has been no record of activity related to meliponiculture among residents of the Itamarati settlement. These bees develop spontaneously, making their nests in the corrals, in the trees, or in the farmers' own houses, in cavities in the ground, cracks in houses, and holes in the building bricks; thus, they resort to the flowers of the passion fruit orchard as an area of foraging (Freitas, 2003).

Regarding the occurrence of *X. frontalis* nests, a smaller number were found in the first sampling, suggesting that the recorded bees originated from nesting areas around the orchard. The flowering of *S. lycocarpum* started between the end of October and the beginning of November, and from that moment on, the nesting sites in the orchard showed linear growth until the sixteenth sampling, suggesting that the plants of *S. lycocarpum* had a positive effect on the nesting of *X. frontalis* bees.

At the end of the experiment, the passion fruit orchard showed low vigor in virtually all quadrants, and the permanence of bees at that location was maintained by the presence of *S. lycocarpum*. Therefore, it is evident that the presence of *S. lycocarpum* positively influences the attraction and permanence of pollinating bees during passion fruit cultivation. Similar results have been reported by Silva et al. (2014).

The year-round flowering of *S. lycocarpum* contributed to increased foraging activity and nesting of *X. frontalis* in the study area. Their preferred nesting sites were the posts of the passion fruit orchard and the support structures of the trap nests, both of which were eucalyptus (Mirtales: Myrtaceae). These results corroborate those of Benevides et al. (2009), who inferred that posts in passion fruit orchards serve as an important substrate for nesting *Xylocopa*, promoting its permanence in the cultivation area. The bamboo fragments left as trap nests were discarded by individuals of the genus *Xylocopa* because there were no nests in the bamboo. These results differ from those of Marchi and Melo (2010) and Silva et al. (2014), who observed *Xylocopa* nesting in pieces of bamboo used as trap nests.

Conclusion

Plants of *S. lycocarpum* close to the yellow passion fruit orchard positively influenced the attraction of pollinating bees. In addition, *S. lycocarpum* plants contributed to increased nesting in the passion fruit orchard, providing bees with greater permanence in the cultivated area, a factor that can increase the productivity of the cultivar. Trap nest implementation did not have a positive effect on *X. frontalis* nesting. These bees preferred to build their nests on eucalyptus stakes that supported passion fruit plants, and on orchard posts. The period of greatest foraging activity of the bees was between 1:30 pm and 4:30 pm, indicating that crop management (e.g., application of insecticides) can be carried out in the early hours of the day without interfering with the foraging activity of pollinating bees. This study highlights the importance of integrated management practices that incorporate native plants, such as *S. lycocarpum*, to enhance pollinator diversity and abundance and, consequently, boosts agricultural productivity, promoting more sustainable and efficient crop systems.

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