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RESEARCH ARTICLE - BEES

Flight Activities of *Melipona* (*Melikerria*) *fasciculata* Smith, 1854 (Apidae: Meliponini) in Migratory Meliponiculture

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Abstract

The breeding of stingless bees (meliponiculture) often involves exchanging and selling nests and, sometimes, migrating colonies to take advantage of blooms in different locations. In this study, we analyzed the flight activities of *Melipona fasciculata* in the eastern Amazon region, before and after the migration of colonies in two municipalities in Maranhão, Brazil. The experimental analysis occurred over three periods: P.I (Palmeirândia), P.II (5 days after migration to Governador Nunes Freire), and P.III (30 days after P.II in Governador Nunes Freire). Flight activity was observed in three colonies for three consecutive days per period. The workers were active in the external environment all day (6 am to 5 pm), ceasing after 6 pm. The comparisons between the periods showed that after the transfer, there was an increase in the external activities of exit and pollen, although they did not differ statistically, being significant only for resin and clay. Correlation analysis with the time of day showed that exit behavior was most active in the morning. Nectar was the most exploited resource by the workers in all periods, followed by pollen, clay, and resin. The circular analysis showed a concentration of pollen and nectar collection between 9:30 am and 11:11 am, with these resources being collected earlier in P.II. The results show that the bees adapt quickly to the migration environment, reaching stabilization and similarity to their place of origin in a short time.

Introduction

The Meliponini tribe (Hymenoptera: Apidae, Apinae) includes social bees with an atrophied sting without a defense function. It is estimated that there are 605 species of this tribe worldwide (Engel et al., 2023), with 259 species recognized in Brazil (Nogueira, 2023). Notoriously, stingless bees play a fundamental ecosystem role in pollinating native flora and crops (Khalifa et al., 2021; Bueno et al., 2023).

Meliponiculture, the practice of raising these stingless bees, has gained prominence in the market, arising from its recreational aspect (Quezada-Euán et al., 2022) and for the obtention of bee products such as honey, cerumen, resin, and pollen, depending on the species (Cortopassi-Laurino et al., 2006), constituting a source of income for many traditional families, due to the ease of management and need for little investment. Another economic gain for breeders is the sale of colonies obtained through the multiplicative management of nests (Maia et al., 2015).

One practice with economic potential is the so-called migratory meliponiculture, which, like beekeeping, relocates colonies to capitalize on blooms in different regions, thereby increasing bee products and pollination of native and cultivated species throughout the year (Alves, 2012; Assad et al., 2018). However, this can lead to a denser population of these animals in a new location and cause ecological imbalance in biodiversity, due to food competition with other species that already exist in the new region (Assad et al., 2018).

Therefore, meliponiculture should be regulated to prevent commercialization and migration to areas where the species does not naturally occur (Quezada-Euán et al., 2022).

According to Villas-Bôas (2018), stingless bees are highly dependent on their local environment, a factor closely linked to the climate and floral resources available in their natural habitat. Therefore, to move these animals, it is necessary to ensure that the colony's needs are met and that they do not experience stress, which could compromise the development of the nest. A straightforward and practical method for monitoring the adaptation and behavior of bees is to observe their external flight activities, as this is a biological parameter that can be easily assessed in the field (Leão et al., 2024). These activities include collecting food, such as pollen and nectar, gathering materials to build the nest, including resin and clay, and cleaning the colony (Souza et al., 2006). Foraging depends on the supply of floral resources available at the site and the conditions in which the colony is located, such as food reserves, queen productivity, temperature, humidity, luminosity, etc. (Hilário et al., 2000; Pierrot & Schlindwein, 2003; Freitas et al., 2023a).

As it is a common practice to sell and move stingless bee species, knowledge of the behavioral biology of each species in different places where they are introduced is required. One of the most widely managed native species in Brazil is *Melipona* (*Melikerria*) *fasciculata* Smith, 1854, popularly known as "tiúba", "jandaíra-preta-da-Amazônia", and "uruçú-cinzenta". This endemic Brazilian species occurs naturally in the states of Maranhão, Mato Grosso, Pará, Piauí, and Tocantins (Camargo et al., 2023), and is gaining prominence among breeders in the Amazon region due to its high production capacity, reaching up to 4.4 liters of honey per colony per year (Venturieri et al., 2003), or even equivalent production in around 60 days in migratory meliponiculture (Kerr, 1996).

The current study utilized *M. fasciculata* in a migratory meliponiculture experiment to compare the bees' flight activities in a locality where they had been managed for many years and after relocating them to a new area. The study considered that the two regions are more than 100 km apart, but are still within the Eastern Amazon of Maranhão, the natural distribution area of the species.

Materials and Methods

Study area

The study was carried out in two municipalities in Maranhão, Brazil: Palmeirândia (2°42'11" S; 44°53'46" W) and Governador Nunes Freire (2°9'26" S; 45°49'39" W) (Fig 1). The first town is part of the Baixada Maranhense (Northern Mesoregion of Maranhão), which is characterized by its flooded fields and extensive breeding of *M. fasciculata* in several municipalities (Farfan et al., 2023), while the second town, located approximately 120 km from the first, is part of the Lower Turi region (Western Mesoregion of Maranhão), where beekeeping is quite extensive (Freitas et al., 2023b). Both locations are in the Brazilian Legal Amazon (IBGE, 2021).

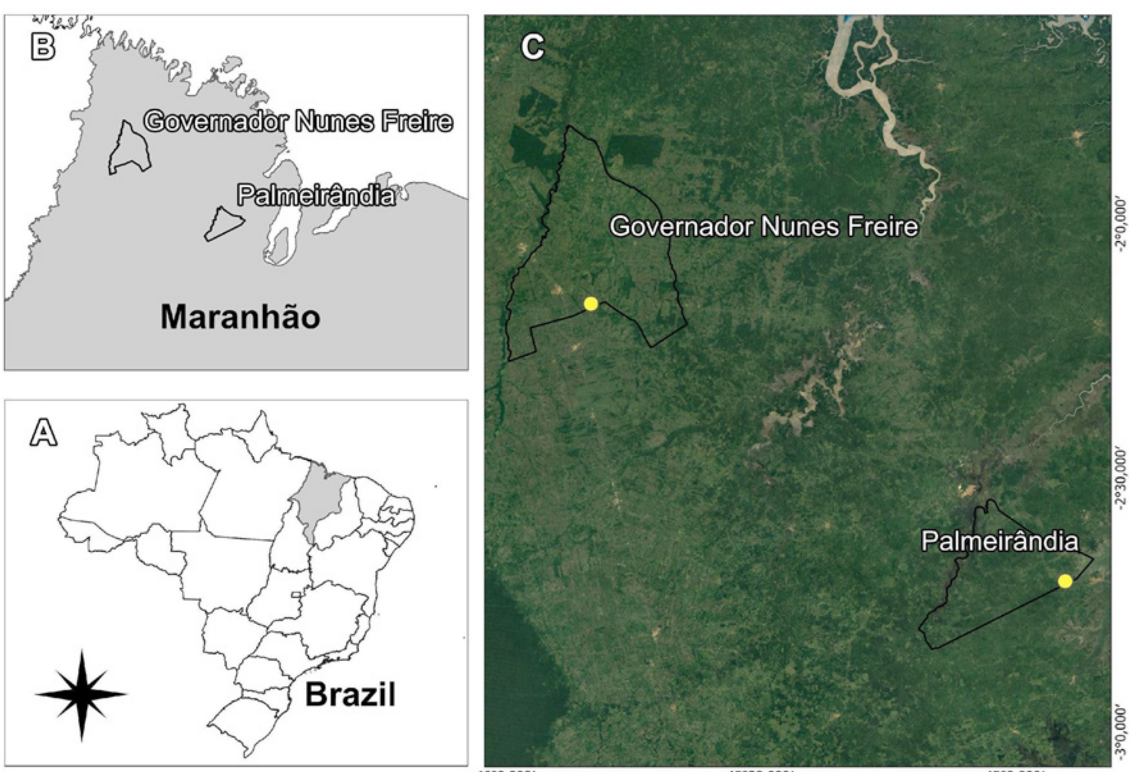

Fig 1. (A, B) Location of the study areas in the state of Maranhão, Brazil: (C) Palmeirândia and Governador Nunes Freire.

The predominant climate in the localities is Tropical Humid (AW' classification by Köppen), under the influence of the Continental Equatorial Mass, characterized by two seasons, one rainy and one dry. The relative humidity ranges from 77% to 82%, the average daily temperature varies from 22.6 °C to 34 °C, and the annual rainfall is between 1600 mm and 2500 mm, with the wettest season occurring in the first half of the year (Sousa & Zonta, 2020).

Data collection

The research was conducted with three *M. fasciculata* colonies between May and June 2023. The procedure took place over three periods, and in each period, the flight activities of the worker bees at the entrance to the nests were observed (Fig 2).

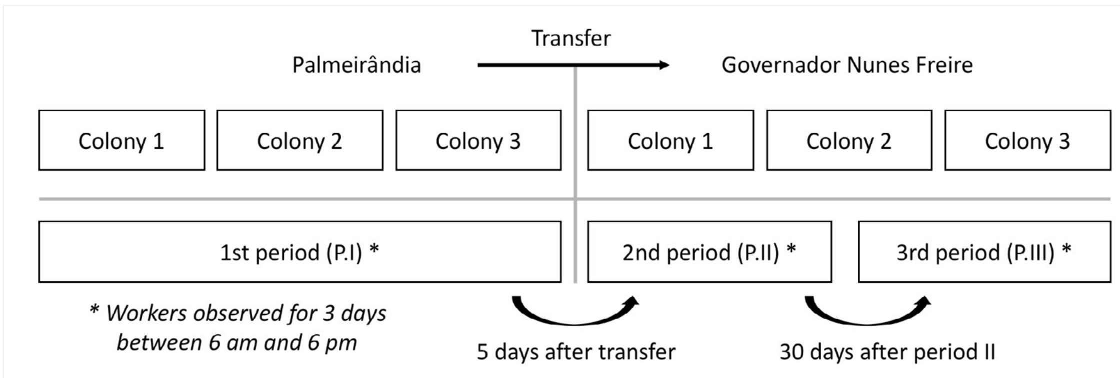

Fig 2. Procedure for analyzing the flight activities of *Melipona fasciculata* colonies, in Palmeirândia (P.I), and after transfer to Governador Nunes Freire (P.II and P.III), in Maranhão, Brazil.

The first period (P.I) took place in the municipality of Palmeirândia, where the colonies were in the meliponarium of a local breeder. After observation, the colonies were sealed and transferred to a new meliponarium in the municipality of Governador Nunes Freire, where the species had not been previously recorded. The second period (P.II) was instigated five days after the transfer to give the colonies time to acclimatize. The third period (P.III) occurred 30 days after the previous stage. In this final period, the workers consisted of new individuals due to the natural death of the foragers (Gomes et al., 2015; Gostinski et al., 2017).

Observations were made for 3 days per period (total = 9 days of observation). The procedure in each colony took place between 6 am and 6 pm, with a duration of 5 minutes per hour. Flight activities were characterized, according to Hilário et al. (2000), by the number of:

(A) bees returning with nectar, with no apparent material in the corbiculae,

(B) bees returning with pollen,

(C) bees returning with clay,

(D) bees returning with resin,

(E) bees leaving the colony with debris – cleaning,

(F) bees leaving the colony without a load – exit.

Data analysis

One-way ANOVA (F) analysis was used to verify the difference in the bees' flight activities between the three periods (I - before, II, and III - after transfer). This analysis was followed by Tukey's post hoc test to identify specific changes between periods (p = 0.05).

Spearman's non-parametric test (r_s) was used to verify the correlation between the times of day and the flight activities of the workers (collecting nectar, pollen, clay, resin, leaving with debris, and leaving without load), with a significance level of 5%. Abiotic data were not tested, as the climatic conditions and temperature range were not significantly different between the two locations, and the procedure took place over 45 days.

A circular analysis was conducted to assess the occurrence of preferential hours in the bees' activities, considering the total number of bees engaged in their specific activities during each period. The analysis was carried out using the Oriana program, version 4. The other tests were carried out using the Past program, except for the circular analysis.

Results

Observations of *M. fasciculata* workers revealed that their flight activities occurred throughout the day, between 6 am and 5 pm, in both locations analyzed: Palmeirândia and Governador Nunes Freire. Observations after 6 pm showed that the foragers no longer left the nest, due to low light (Fig 3).

The comparisons between periods P.I (Palmeirândia), P.II, and P.III (Governador Nunes Freire) demonstrated that immediately after the transfer, the behavior of leaving and collecting resources such as pollen, clay, and resin increased, but that leaving without a load in P.III was closer to the values observed in the locality where the nests originated (Fig 4).

The analysis of variance (one-way ANOVA) showed no significant changes between the three periods in nectar collection (F = 0.311; p = 0.734), pollen collection (F = 0.751;

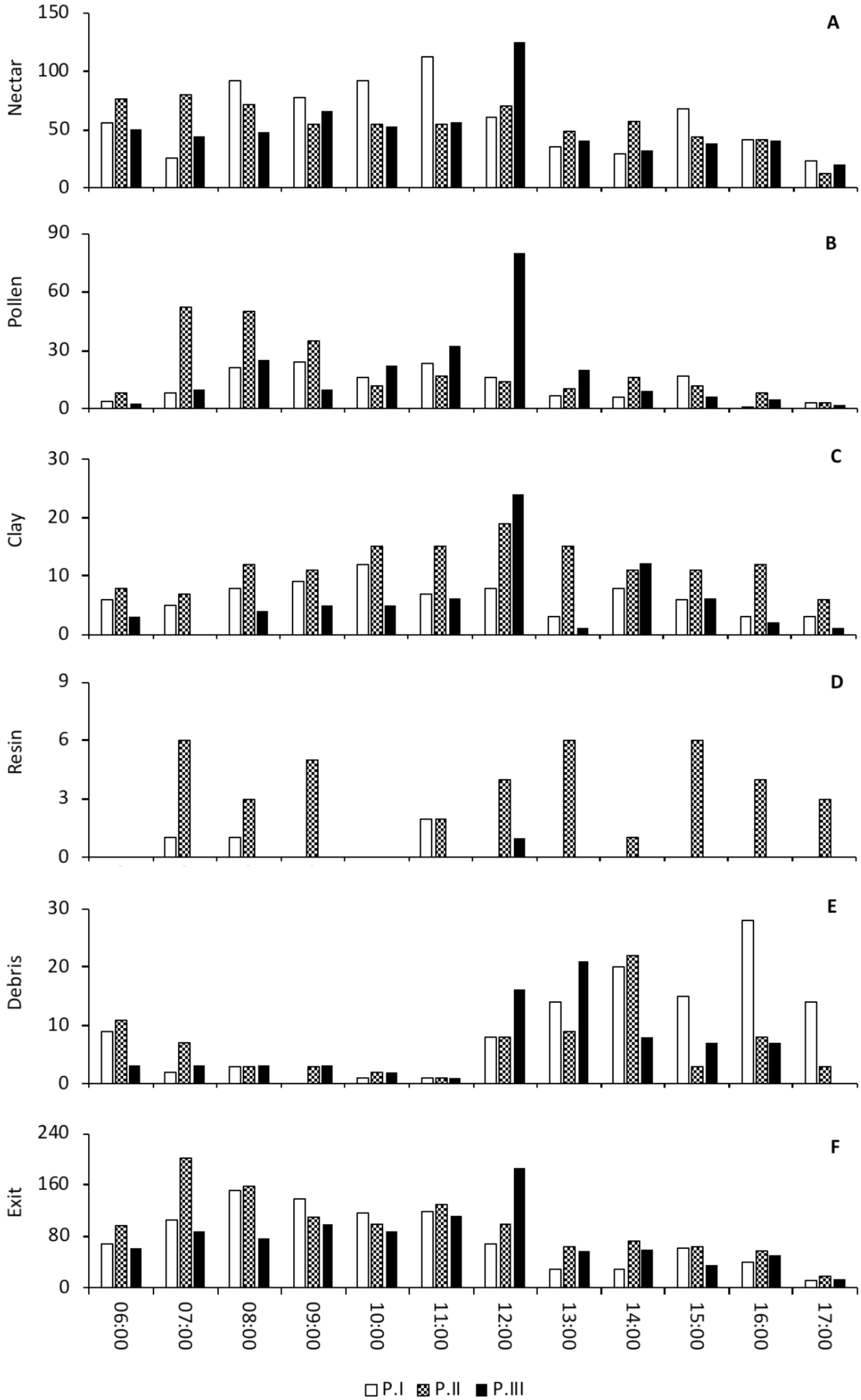

Fig 3. Total number of *Melipona fasciculata* workers in flight activities in the three periods: P.I (Palmeirândia), P.II and P.III (Governador Nunes Freire), from 6 am to 5 pm. (A) Nectar, (B) Pollen, (C) Clay, (D) Resin, (E) Leaving with debris, and (F) Exit – Leaving without load.

p = 0.479), exit behavior – leaving without a load (F = 0.745; p = 0.482), and nest cleaning – leaving with debris (F = 0.805; p = 0.455) (Table 1). However, comparing the data (period to period) using Tukey's test showed that the collection of clay and resin changed significantly, especially between P.I - P.II and P.II - P.III ($p < 0.05$) (Table 1), since the collection of these materials increased after the migration of the colonies, but then returned to values similar to the place of origin.

Overall, the workers most explored nectar in all periods, followed by pollen, clay, and resin (Fig 4). The correlation analysis between flight activities and observation times indicated that only exit behavior was related to the time of day in all three periods, with the highest external activity of these bees in the morning (Table 2). Only in P.II (5 days after transfer), there was a correlation with the morning shift in the collection of nectar ($r_s = -0.852$; p = 0.0004) and pollen ($r_s = -0.625$; p = 0.029). The cleaning activity was correlated with the time of day only in P.I, where more workers were seen carrying out this activity in the afternoon ($r_s = 0.684$; p = 0.014).

The circular analysis to verify the average time the workers were most concentrated in their flight activities demonstrated most activity between 9:15 am and 2:15 pm, depending on the activity carried out (Table 3; Supplementary material). Immediately after the transfer (P.II), the average time spent collecting pollen and nectar was shorter than in other periods. This observation confirms the data from the correlation analysis. Another example is the average cleaning time, which at P.I (2:15 pm) was later, but was brought forward after the transfer of location.

Table 1. Analysis of variance between the activities of *Melipona fasciculata* workers in the three periods - P.I (Palmeirândia), P.II and P.III (Governador Nunes Freire).

Flight activity		P.I	P.II	F	P-value
Nectar				0.311	0.734
	P.II	0.552			
	P.III	1.116	0.564		
Pollen				0.751	0.479
	P.II	1.603			
	P.III	1.374	0.228		
Clay				6.094	0.005
	P.II	3.969*			
	P.III	0.558	4.528*		
Resin				21.5	0
	P.II	7.691*			
	P.III	0.64	8.332*		
Leaving with debris				0.805	0.455
	P.II	1.419			
	P.III	1.662	0.243		
Leaving without load				0.745	0.482
	P.II	1.415			
	P.III	0.148	1.564		

*Tukey's test with $p < 0.05$.

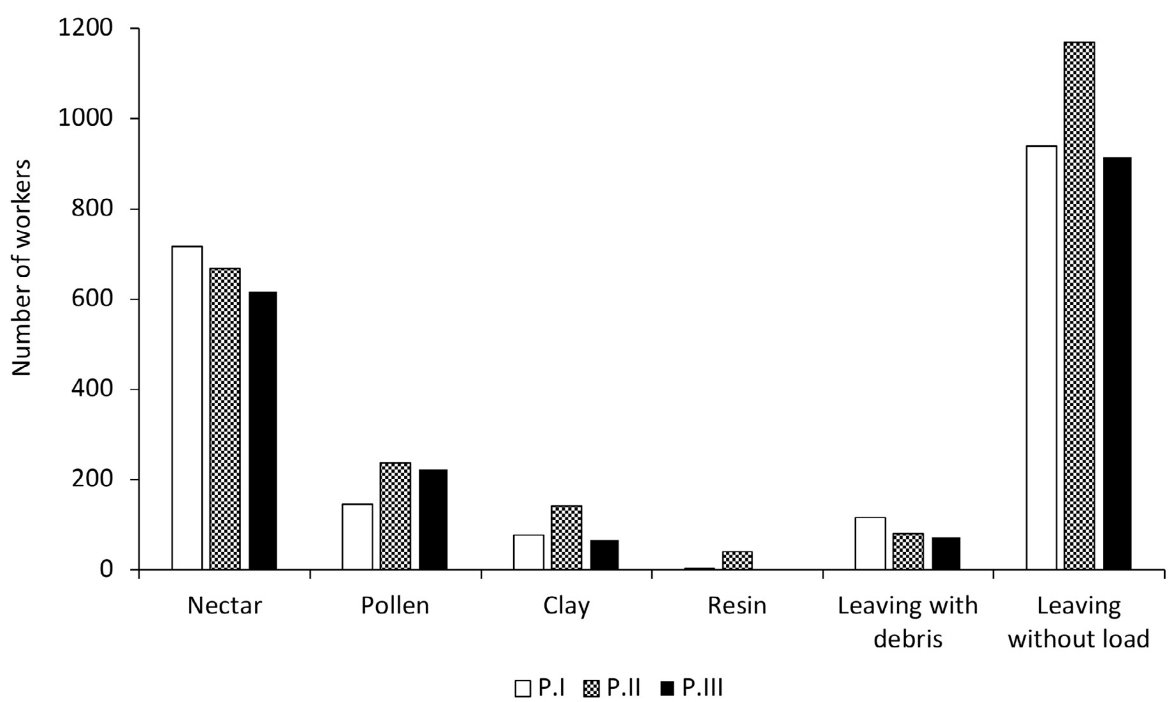

Fig 4. Total number of *Melipona fasciculata* workers in flight activities in the three periods: P.I (Palmeirândia), P.II and P.III (Governador Nunes Freire).

Table 2. Spearman's correlation analysis (r_s) of the flight activities of *Melipona fasciculata* concerning the observation times (6 am to 5 pm), in the three periods - P.I (Palmeirândia), P.II and P.III (Governador Nunes Freire).

	Nectar	Pollen	Clay	Resin	Leaving with debris	Leaving without a load
P.I	-0.258	-0.399	-0.422	-0.437	0.684*	-0.740*
P.II	-0.852*	-0.625*	0.0042	0.187	-0.016	-0.819*
P.III	-0.277	-0.329	0.101	0.043	0.203	-0.629*

*P-value significant at 5%.

The Rayleigh test was not significant only for resin collection in period P.III, indicating that this resource did not show a statistically relevant hourly concentration pattern. All the r vectors showed values above 0.500, which indicates a greater concentration of the number of workers around the mean of the vector (Table 3).

Discussion

Observations of the flight activities of *M. fasciculata* in the initial area and at the migration site showed that the workers only carried out their external activities during the day, ceasing after 6 pm. This activity pattern occurs because light affects the start and end of colonies leaving for foraging (Souza et al., 2006; Ferreira Junior et al., 2010; Moura et al., 2022).

The displacement of *M. fasciculata* colonies to a new site, to assess their adaptations based on flight activities, showed that soon after the transfer (P.II), there was an increase in the collection of clay and resin. The search for these nest-building materials was significantly different between the analyzed periods, as demonstrated by ANOVA and Tukey's test. Perhaps the displacement between the two locations caused damage to the geopropolis that seals the nests, leading to the compensation of these resources in a short period (Gostinski et al., 2017).

Table 3. Circular analysis applied to the number of *Melipona fasciculata* bees to verify the time of greatest probability of flight activities in the three periods (before and after transfer).

Flight activity	Period	Hour	Average vector (μ)	Length of the mean vector (r)	Rayleigh test (Z)
Nectar	P.I	10:47	161.933°	0.724	375.014*
	P.II	10:28	157.063°	0.68	308.438*
	P.III	11:00	165.104°	0.718	318.744*
Pollen	P.I	10:37	159.366°	0.782	89.317*
	P.II	09:30	142.566°	0.748	132.659*
	P.III	11:11	167.753°	0.852	162.585*
Clay	P.I	10:47	161.857°	0.717	40.116*
	P.II	11:35	173.829°	0.718	73.277*
	P.III	11:56	179.135°	0.819	46.309*
Resin	P.I	09:15	138.871°	0.893	3.19*
	P.II	12:01	180.461°	0.655	17.163*
	P.III	12:00	180°	1	1
Leaving with debris	P.I	14:15	213.93°	0.743	63.536*
	P.II	12:06	181.734°	0.635	32.255*
	P.III	12:33	188.299°	0.802	47.648*
Leaving without load	P.I	09:52	148°	0.76	542.442*
	P.II	09:57	149.428°	0.716	599.284*
	P.III	10:43	160.79°	0.756	523.659*

*P-value significant at 5%

Statistical analysis revealed no differences between the three periods in the activities of collecting food resources and the workers' departure. However, some changes were observed in the number of workers carrying out these activities after migration, as seen in Figure 4, and there was stabilization in the workers' behavior in P.III, resembling the area of origin. The rapid adaptation of the colonies to the new region may be due to the efficient location of new sources by recruiting bees, a behavior well described for stingless social bees (Hrncir et al., 2008; Hnrcir & Maia-Silva, 2013), which decide on the food resource in a short time, allowing for daily surveys (Jesus et al., 2014).

Other reasons may be that the new environment does not differ significantly from the previous one in terms of beekeeping potential, as Governador Nunes Freire has typical Amazonian vegetation similar to Palmeirândia. Additionally, the time of year is a factor, as both locations were in the rainy season, which influences the bees' external activities. Mascena et al. (2018) and Farfan et al. (2023) demonstrate that bee activity patterns are related to edaphoclimatic conditions and landscape composition.

The higher activity of bees leaving the colonies occurred during the morning shift in all periods, as verified by Spearman's correlation analysis and circular analysis, which may be related to the greater availability of floral resources at this time of day, or to avoid competition with other animals looking for the same resources throughout the day (Bruijn & Sommeijer, 1997), and due to temperature variations, which affect flight activities as the hours go by (Roubik, 1989). Additionally, a significant Spearman's correlation was found between nectar and pollen collection and the morning shift only in P.II, possibly because the workers were recognizing and exploring floral sources in the new location, with the potential recruitment of bees to optimize foraging earlier.

In general, it has been found that pollen collection by *Melipona* bees predominates in the morning (Souza et al., 2006; Oliveira et al., 2012; Freitas et al., 2023a). The circular analysis also revealed a more concentrated collection during this time. The collection peak at midday in P.III was similar to that seen for *M. fasciculata* in the cerrado, where pollen collection increased between 10 am and 2 pm (Xavier de Freitas et al., 2020).

Regardless of the location or period analyzed, nectar was the most collected resource by the workers, which coincides with that found for species of the genus *Melipona* (Ferreira Junior et al., 2010; Oliveira et al., 2012). The fact that the collection of this resource did not differ between the periods is undoubtedly due to the nests having sufficient stocks of honey and not needing to increase foraging, as the availability of resources in the nests influences the collection of resources (Gostinski et al., 2017).

In our data, nectar foraging occurred throughout the day, but with an even greater concentration in the morning shift, which differs from that seen for the species in the cerrado, where collection increased in the afternoon (Xavier de Freitas et al., 2020). According to Corbet (2003), due to evaporation, caused by the decrease in air humidity and increase in temperature, the nectar in flowers becomes more concentrated in sugars throughout the day, so the workers increase their collections at later times of the day in order to obtain a resource with better quality of solutes. It is possible that because the research was carried out in rainy months, the workers anticipated their activities due to the likelihood of rain in the region during the afternoon shift. However, this is only a supposition, since rain did not affect the days when this study was carried out.

Nest cleaning during the afternoon shift was significant in P.I, similar to what was found by Pereira et al. (2006). As the cleaning data did not correlate with the time of day in P.II and P.III, we believe this behavior is highly variable according to the internal conditions of debris storage.

The data show the species' adaptation, which favors the practice of meliponiculture. This activity should be encouraged, as it promotes income for breeders and optimizes the ecosystem service of pollinating native and cultivated plants (Kerr, 1996). Furthermore, it conserves stingless bees, which are rapidly declining due to habitat loss, climate change, the introduction of exotic species, pathogens, and chemical pesticides (Toledo-Hernández et al., 2022). However, it is worth noting that the introduction of colonies in new locations can impact the ecological network of the native fauna in the introduction region (Quezada-Euán et al., 2022). For Nogueira-Neto (1997), the migration of stingless bees has a positive aspect, as it takes advantage of blooms that do not coincide with the location of the meliponary installation, and has a low impact when compared to *Apis mellifera*, since their populations are much smaller.

Conclusions

Understanding how bees adapt to the regions where they are found helps provide the right conditions for nest survival, with abundant long-term supplies and reduced stress effects. In this migratory meliponiculture experiment, it is evident that the bees quickly adapted to the new environment, thereby optimizing the exploitation of essential resources, including pollen, resin, and clay. However, they soon stabilized their behavior to the values characteristic of their place of origin. Due to the efficient exploitation of resources in the new location, there was no apparent shortage of supplies. A long-term study could provide more insight into the increase in honey production by the colonies. In the case of *M. fasciculata*, the species naturally occurs in the geographical area analyzed, so we believe that the effects of introduction are minimized. Consequently, this practice promotes the rational use of bees to achieve the desired socio-economic and environmental benefits. Nevertheless, meliponiculture and colony migration practices must adhere to the legislation in effect in each country.

Authors' Contribution

SLSS: Conceptualization, investigation, data curation, formal analysis, visualization, and writing-original draft.
RSP: conceptualization, supervision, methodology, formal analysis, validation, visualization, writing-review & editing.

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