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Factors affecting the use and preference of stingless bees in the state of Rio de Janeiro, Brazil: implications for conservation

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ABSTRACT

Meliponiculture plays an essential role in the conservation of stingless bees and the maintenance of biodiversity. This study investigated the factors influencing the use and preference for stingless bee species in the state of Rio de Janeiro, Brazil. The species managed and preferred by meliponiculturists were identified, and the influence of socioeconomic and environmental variables on the diversity of managed species was evaluated. Forty-three meliponiculturists were interviewed, reporting a total of 38 managed species. The results indicated that the most managed species were also the most preferred, with *Tetragonisca angustula*, *Melipona quadrifasciata*, and *Melipona mondury* being the most frequently cited. The primary criteria for species selection were ease of management, productivity, and behavior, while financial factors had less influence. Years of experience, education level, and marital status were determining factors in the diversification of managed species. However, the level of involvement in meliponiculture, the number of products sold, and the location of the meliponiculturists (urban or rural areas) did not significantly impact the diversity of raised bees. Although meliponiculture promotes conservation efforts, the management of non-native species to the Atlantic Forest biome requires attention due to potential ecological impacts. The findings of this study can contribute to the development of sustainable management and conservation strategies for stingless bees in Brazil.

Keywords: Biodiversity, Conservation, Ethnobiology.

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SIGNIFICANCE STATEMENT

This study reveals the cultural, socioeconomic, and ecological motivations behind stingless bee selection by meliponiculturists in Rio de Janeiro, Brazil, filling a critical gap in understanding how human preferences influence conservation efforts. By integrating utilitarian and emotional criteria, we demonstrate the risks of introducing non-native species into the Atlantic Forest biome. Our findings underscore the vital role of local ecological knowledge in fostering socio-ecological resilience and provide actionable insights for policymakers and institutions to support sustainable meliponiculture and stingless bee conservation.

INTRODUCTION

The ecological services provided by bees are essential for maintaining ecosystem balance, making them a focal point of interest in ecology and conservation studies. In Brazil, this group of insects is abundant, with over 1960 described species (Moure et al. 2022). Native Brazilian bees of the Meliponini tribe are commonly referred to as "meliponines," "stingless bees," or "indigenous bees." This group of neotropical social bees produces honey and is characterized by an atrophied or absent stinger, which is used only as an ovipositor by queen bees (Michener, 2007). There are over 600 described species of stingless bees worldwide (Engel et al., 2023), approximately 250 of which are found in Brazil (Nogueira, 2023).

Pollination contributes to improved seed and fruit production, thereby supporting the maintenance of native vegetation (Kerr et al. 1996; Maués, 2001; Moreira et al. 2015). In Brazil, native stingless bees are responsible for pollinating approximately 30% of plant species in the Caatinga and Pantanal biomes and up to 90% in some areas of the Atlantic Forest and parts of the Amazon (Kerr et al. 2001). The Thematic Report on Pollination, Pollinators, and Food Production in Brazil (Wolowski et al. 2019) highlighted that 76% of the plants used for food production in the country depend on pollination services, which were estimated at R$43 billion in 2018, with 80% of this value associated with crops of significant agricultural importance. Thus, bee conservation is crucial for ensuring food security and income for agricultural producers, contributing to a healthy life and promoting human well-being (Wolowski et al. 2019; Garibaldi et al. 2016; Novais et al. 2016).

The breeding of native stingless bees, known as meliponiculture, has been practiced for centuries by Indigenous Peoples and local communities, quilombolas (afrodescendant communities), and farmers (Carvalho et al. 2014) in neotropical regions. This practice encompasses activities such as hunting, honey collection, and the management of colonies (Crane, 1999). These interactions have been documented in ethnobiological and ethnoecological studies, which have primarily focused on local knowledge and practices (Carvalho et al. 2014; Posey, 1982; Posey and Camargo, 1985; Reyes-González et al. 2014), local taxonomy (Costa-Neto, 1998; Zamudio and Hilgert, 2012a), symbolic-cosmological aspects (Léo-Neto and Grünewald, 2014; Santos and Antonini, 2008), and factors influencing the selection and preference for certain species (Carvalho et al. 2018; Reyes-González et al. 2014).

In the field of ethnobiology, few studies have sought to understand the factors influencing the choice and preference of meliponiculturists for certain species of stingless bees. Human preferences for specific elements of biodiversity play a significant role in shaping attitudes and behaviors toward nature conservation (Carvalho et al. 2018; Kaltenborn et al. 2006; Stokes, 2007). Consequently, the effectiveness of conservation efforts may depend on how much these species are valued or disregarded by people (Kaltenborn et al. 2006). For useful species, it is essential to understand the underlying values that drive their use and preference (Carvalho et al. 2018; Stokes, 2007).

Testing the biophilia hypothesis, Carvalho et al. (2018) found that emotional criteria drive the keeping of stingless bees in a quilombola community in the state of Pernambuco, Brazil. However, these criteria were not decisive in species preference, which was also influenced by utilitarian and economic factors (Carvalho et al. 2018). Reyes-González et al. (2014) observed that the bees with the highest importance index for meliponiculturists in Michoacán, Mexico, were those whose honey, wax, and pollen were the most preferred products. Similarly, in Guerrero, Mexico, Gonzalez et al. (2018) found that the most versatile bees-those with the greatest number of uses and, consequently, the highest cultural importance index-were also the most abundant in the region. This association was also observed in a study conducted in Misiones, Argentina, where the authors used the perceived abundance of nests as a metric (Zamudio and Hilgert, 2018).

Socioeconomic and environmental factors can also influence the knowledge and diversity of managed bee species. Variables such as experience, marital status, education level, and a closer relationship with the environment have been identified as important drivers of knowledge about plants and animals in ethnobiological studies (Campos et al. 2019; Rêgo et al. 2021; Silva et al. 2019), including those focusing on stingless bees (Bhattacharyya et al. 2017; Jaffé et al. 2015; Masuku, 2013).

Studies suggest that formal education may influence the knowledge and use of natural resources, as time spent in school or university can reduce opportunities for interacting with and learning about biodiversity (Medeiros et al. 2012; Reyes-García et al. 2010). This points to a potential negative relationship between schooling and local ecological knowledge (Ruan-Soto 2018; Santos et al. 2020; Souza et al. 2024). In the context of meliponiculturists, Bhattacharyya et al. (2017) found that educational level was positively associated with the ability to identify native bee species in India.

Regarding marital status, this social condition has been found to relate positively with local knowledge (Baana et al. 2018) and with engagement in beekeeping activities (Andaregie and Astatkie 2021). A similar pattern is observed when considering the variables of experience and occupation. Individuals with more experience (Jaffé et al. 2015) and those engaged in nature-related occupations (Ruan-Soto 2018) tend to exhibit higher levels of local knowledge, as these conditions promote direct contact with natural elements.

To better understand the factors associated with the selection and preference for native stingless bees in the state of Rio de Janeiro, the objectives of this research were: (i) to record the species managed and preferred by meliponiculturists in different regions of the state; (ii) to verify whether the most managed species are also the most preferred; (iii) to identify the most important criteria for species preference (aesthetics, behavior, products, management, financial factors, and conservation) (iv) to determine whether the number of managed species is influenced by years of experience, education level, marital status, and the number of products sold by meliponiculturists; (v) to identify whether there are differences in the number of managed species between meliponiculturists in rural and urban areas and among those with different levels of involvement in meliponiculture (primary occupation, secondary occupation, and hobby); and. Our hypotheses are: (i) the most managed stingless bee species are also the most preferred; (ii) the number of managed species is significantly influenced by years of experience, education level, marital status, and the number of products sold; (iii) rural meliponiculturists manage a significantly greater number of species compared to those in urban areas; and (iv) meliponiculturists for whom meliponiculture is their primary occupation manage a significantly greater number of species compared to those who practice it as a secondary occupation or hobby.

MATERIAL AND METHODS

Study area

The study was conducted in the state of Rio de Janeiro, characterized by a complex mosaic of natural environments-both physical and biotic-that have been significantly transformed by human activities. To guide the sampling strategy and ensure the selection of meliponiculturists from across the widest possible range of regions within the state, we adopted the geoenvironmental classification proposed by Dantas et al. (2000), which identifies six distinct domains based on factors such as vegetation cover and agricultural suitability: Geoenvironmental Domain I (Metropolitan Region, Lakes Region and Northern Fluminense Region), Geoenvironmental Domain II (Mountain Region), Geoenvironmental Domain III (Mountain Region Plateau), Geoenvironmental Domain IV (Middle Paraíba do Sul River Valley Depression), Geoenvironmental Domain V (North-Northwest Fluminense Depression) and Geoenvironmental Domain VI (Upper Itabapoana Plateau). The sample included 26 municipalities, covering all Geoenvironmental domains except Domain VI (Figure 1).

Selection of informants and data collection

The project was approved by the Research Ethics Committee (CEP) through the Plataforma Brasil under permission number CAAE 67022223.3.0000.5108. All selected informants who agreed to participate in the study were invited to read and sign the Informed Consent Form (Termo de Consentimento Livre e Esclarecido – TCLE), authorizing the collection, use, and publication of the data obtained. Thus, all procedures related to this research comply with Resolutions No. 466/12 and 510/16 of the Brazilian National Health Council for research involving human subjects. Additionally, the project was registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) (registration number A8A5B42).

The identification of meliponiculturists was initially conducted through contact with the Association of Meliponiculturists of Rio de Janeiro (AME-Rio), an organization founded in 2007 that plays a significant role in the development of the meliponiculture in the state of Rio de Janeiro. We attended one of the association's meetings and presented the project, which helped us establish initial contact with meliponiculturists. Additional contacts were made through online searches on websites such as www.abelhas.org, Google Maps, Instagram, as well as through recommendations from meliponiculturists who had already been contacted and interviewed. Contacts were made via phone calls and/or messages. At this stage, the project was presented, and individuals were invited to participate in the study. In case of acceptance, a date was scheduled for the interview. We aimed to select meliponiculturists who had already started generating income from meliponiculture (or who were organizing to do so) across the six geoenvironmental domains of the state. Our final sample comprised forty-three meliponiculturists interviewed, including only one woman. During the visits, we recorded the socioeconomic profile of the meliponiculturists using semi-structured interviews (Albuquerque et al. 2014). Participants were asked about their level of involvement in meliponiculture (primary occupation, secondary occupation, or hobby) and years of experience in the activity. We also recorded the location where the bees were kept (urban or rural). To ensure better data processing, the meliponiculturist from Ilha Grande was considered a rural resident.

The second part of the interview focused on meliponiculture, with questions such as "How did you

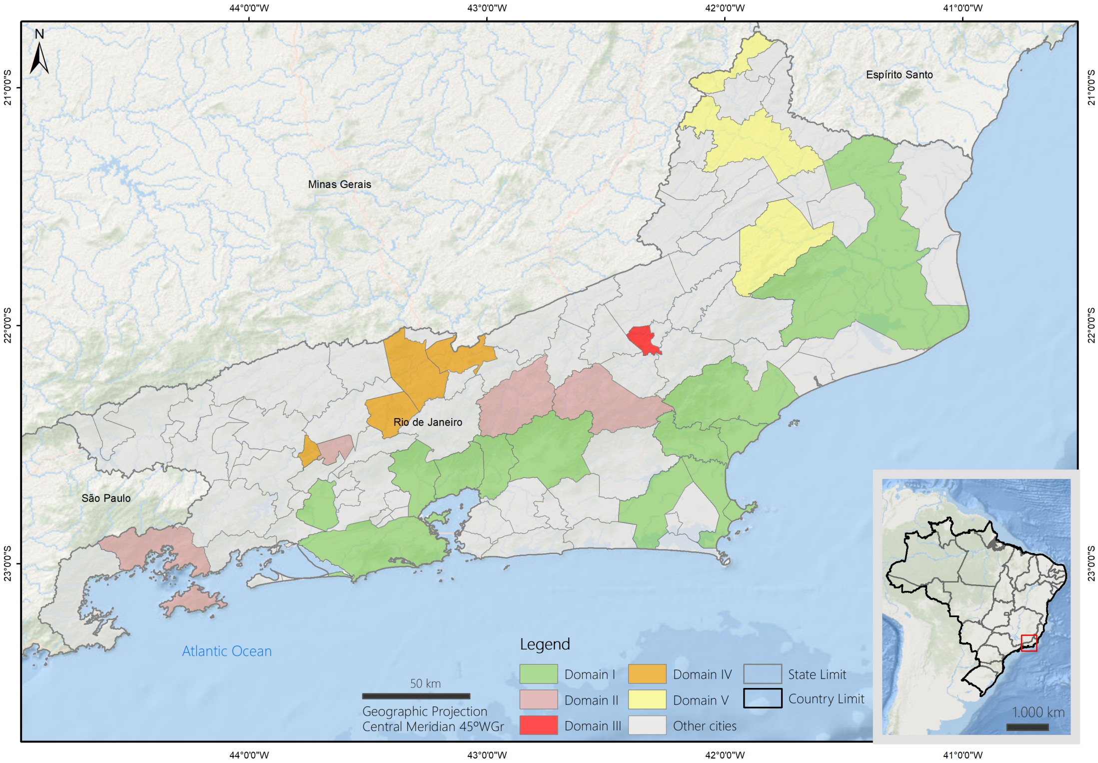

Figure 1. Municipalities and Geoenvironmental Domains of the state of Rio de Janeiro, Brazil, where interviews with meliponiculturists were conducted. Source: the authors.

become interested in this activity? What products do you sell?" We then recorded the species of bees managed, starting with the question: "Which stingless bees do you manage?" Finally, we asked "Which is your favorite bee?" and "Why do you prefer this bee?" At least three specimens of each mentioned bee species were collected with the assistance of the informant. These specimens were identified by experts and subsequently incorporated into the Reference Collection of the Integrated Invertebrate Laboratory (Labin) at UFRJ/NUPEM.

Data analysis

The normality of the data was assessed using the Shapiro-Wilk test, which guided the selection of appropriate statistical tests. Generalized Linear Models (GLMs) were used to assess whether years of experience in meliponiculture, education level, marital status, and the number of products sold by meliponiculturists (explanatory variables) explained the number of species managed (response variable, using a "poisson" family distribution). The education level and the marital status were categorical variables, thus the responses obtained from the interviews were classified according to the following reference levels: (1) Elementary School (incomplete or complete); (2) High School (incomplete or complete); (3) Higher Education (incomplete or complete) for education level; (1) Single/divorced; (2) Married for marital status. We used dummy coding. A correlation matrix was created, and the Variance Inflation Factor (VIF) was calculated for each variable to check for multicollinearity (VIF > 2). A high correlation was observed between age and years of experience, so the age variable was removed from the analysis. All model diagnostics, residual analyses, overdispersion checks, and model comparison procedures (AIC and likelihood ratio tests) are detailed in the Supplemental Material S1.

The Mann-Whitney test was used to evaluate whether there were significant differences in the number of species managed between rural and urban meliponiculturists. To identify significant differences in the number of species managed among interviewees with different levels of involvement in meliponiculture (primary occupation, secondary occupation, or hobby), the Kruskal-Wallis test was applied.

The Spearman Correlation Test was used to determine whether the most preferred bee species were also the most managed by meliponiculturists. To identify the criteria influencing the preference for certain bee species, responses to the question "Why do you prefer this bee?" were categorized into the following groups: (i) aesthetics: responses such as "beautiful," "radiant," "organized nest," etc.; (ii) behavior: responses such as "fast," "hard-working," "calm," "populous swarm," etc.; (iii) products: references to products, regardless of behavior, e.g., "produces a lot of honey," "produces good honey," "produces a lot of pollen," etc.; (iv) management: responses such as "easy to raise," "doesn't cause any work," etc.; (v) conservation: responses such as "native," "is from the region," "is adapted," etc.; (vi) financial: responses such as "good financial return," etc. Each time a criterion was mentioned for a category, it received 1 point. The scores for each preference category were summed to determine the most important criteria for the species cited as preferred by the meliponiculturists. Interviewees were free to cite multiple reasons for their preference.All statistical analyses were performed using R software (R Core Team, 2024), in packages *stats, ggplot2, ggeffects, see, patchwork, DHARMa and forcats.*

RESULTS

Species of stingless bees managed in the state of Rio de Janeiro, Brazil

The 43 meliponiculturists reported a total of 46 common names for managed stingless bees, corresponding to 38 species. Table 1 presents the species managed by the interviewed meliponiculturists, along with the total number of mentions. The most frequently mentioned species were *Tetragonisca angustula* (Jataí), with 43 mentions (reported by all meliponiculturists), *Melipona quadrifasciata anthidioides* (Mandaçaia - MQA), with 40 mentions, and *Melipona mondury* (Uruçu amarela/Bugia), with 32 mentions (Table 1).

Figure 2 shows some of the meliponaries visited during the research.

Socioeconomic and regional factors associated with the diversity of managed stingless bee species

Table 2 presents the socioeconomic profile of the interviewees, along with the categorical and continuous variables used in the statistical analyses.

No substantial overdispersion was detected (dispersion parameter = 1.46), and residual plots showed no violation of assumptions (see Supplemental Material S1). The years of experience, education level, and marital status significantly influenced the number of managed species. Married individuals, those with more experience, and those with a lower level of education tended to manage a greater number of species. In contrast, the number of products extracted from bees was not significantly related to the number of species managed (Table 3 and Figure 3).

No significant differences were observed in the number of species managed among meliponiculturists from different regions ($W = 197.5$; $p = 0.7583$) or among those with different levels of involvement in meliponiculture ($\chi^2 = 1.2667$; $p = 0.5308$).

Preference criteria for stingless bee species

A significant and positive association was observed between the number of citations of managed stingless bees and the number of citations of preferred species by the interviewees, indicating that meliponiculturists tend to prefer species they consider more culturally important ($S = 4408.8$; $r = 0.52$; $p < 0.005$).

Ten stingless bee species were mentioned as preferred, with *M. mondury* (Uruçu amarela/Bugia) being the most reported (13 mentions), followed by *M. quadrifasciata anthidioides* (Mandaçaia - MQA) and *T. angustula* (Jataí), each with 9 mentions (Table 4). A total of 146 criteria related to 6 categories of preference for stingless bee species were reported by the meliponiculturists interviewed. The most important categories to explain the preference for *M. mondury* were products (whose criteria related to this category were mentioned 8 times), management (6 mentions) and behavior (5 mentions). For *M. quadrifasciata anthidioides*, the management category was the most important (7 mentions). Behavior (4 mentions) and management (3 mentions) were the most important categories to justify the preference for the bee *T. angustula* (Table 4).

DISCUSSION

Stingless bee species managed and preferred in the state of Rio de Janeiro, Brazil

The results of this study revealed important patterns in the selection and preference of stingless bee species managed by meliponiculturists in the state of Rio de Janeiro. The high number of stingless bee species managed by meliponiculturists (38) is a positive outcome for nature conservation, as meliponiculturists often exhibit conservationist attitudes (Carvalho et al. 2003). Meliponiculture is considered an activity with a low exploitative impact on natural resources (Jaffé et al. 2015) and encourages behaviors favorable to nature conservation, such as maintaining high plant diversity to provide food resources for these pollinators (Chanthayod et al. 2017; Tolera et al. 2021). However, despite promoting conservation actions, the fact that some bee species mentioned by

Table 1. Scientific names and common names of stingless bee species managed by the meliponiculturists interviewed in the state of Rio de Janeiro, Brazil, showing the total number of citations. n=43.

Species	Common name	Citations
Tetragonisca angustula	Jataí	43
Melipona quadrifasciata anthidioides	Mandaçaia (MQA)	40
Melipona mondury	Uruçu amarela/Bugia	32
Plebeia droryana	Droriana	27
Nanotrigona testaceicornis	Iraí	26
Plebeia lucii	Luci	24
Scaptotrigona bipunctata	Tubuna	23
Plebeia remota	Droriana amarela/Miringuaçu/Miringuaçu amarela	19
Scaptotrigona xanthotricha	Mandaguari amarela	18
Tetragona clavipes	Borá	16
Melipona bicolor	Guaraipo	16
Melipona marginata carioca	Manduri amarela/Manduri carioca	9
Melipona scutellaris	Uruçu nordestina	7
Partamona helleri	Boca de sapo	7
Friesella schrottkyi	Mirim Preguiça	6
Plebeia sp 2	Mirim guerreira/ Mirim boxeadora	6
Scaptotrigona postica	Mandaguari	6
Leurotrigona muelleri	Lambe olhos	4
Paratrigona subnuda	Jataí da terra	3
Schwarziana quadripunctata	Guiruçu/Guiruçu do chão	3
Cephalotrigona capitata	Mombucão	3
Oxytrigona tataira	Caga fogo / Tataíra	3
Melipona compressipes	Tiúba	3
Plebeia sp 3	Miringuaçu preta	3
Frieseomelitta sp	Marmelada	3
Melipona subnitida	Jandaíra	2
Trigona recursa	Feiticeira	2
Melipona quadrifasciata quadrifasciata	Mandaçaia (MQQ)	1
Melipona quinquefasciata	Uruçu do chão	1
Melipona rufiventris	Uruçu amarela	1
Plebeia sp 1	Mirim nigriceps	1
Melipona asilvai	Manduri rajada	1
Plebeia sp 5	Plebeia	1
Frieseomelitta doederleini	Moça branca	1
Plebeia poecilochroa (cf)	Mirim amarela	1
Melipona marginata marginata	Manduri amarela/ Manduri carioca	1
Trigona sp.	Trigona	1
Plebeia sp 4	Mirim mosquito	1

the interviewees do not naturally occur in the Atlantic Forest biome should be viewed with caution. Research shows that stingless bees may face competition for resources due to the introduction of exotic species, such as *Apis mellifera* L. (Agüero et al. 2018; Hung et al. 2019; Jaffé et al. 2019). Additionally, species from other biomes may hybridize with local species, interfering with gene flow and local genetic diversity, which could contribute to population declines or even the extinction of threatened native species (Francisco et al. 2014; Nascimento et al. 2000).

The presence of *Tetragonisca angustula, Melipona quadrifasciata anthidioides*, and *Melipona mondury* among the most managed species highlights the importance of these bees in the state of Rio de Janeiro and the Atlantic Forest biome. *T. angustula* has a wide geographic distribution, occurring throughout most of Brazil and in several South and Central American countries, including Colombia, Ecuador, Peru, Bolivia, Guyana, Suriname, Panama, Costa Rica, and Nicaragua (Quezada-Euán et al. 2018). Studies have shown a significant proportional relationship between

Figure 2. Examples of meliponaries visited during the research in the state of Rio de Janeiro, Brazil. A: Paraíba do Sul. B: Nova Friburgo; C: Araruama; D: Mendes; E: Rio de Janeiro; E: Cabo Frio. Photos: the authors.

the cultural importance of stingless bees and their ecological abundance in Mexico (Gonzalez et al. 2018) and between their perceived abundance and cultural importance in Argentina (Zamudio and Hilgert, 2018). Other studies suggest that the preference for *T. angustula* is related to its versatility of uses (Adler et al. 2023), ease of management (Cortés and Rivas, 2023), and commercially valued honey production, including its medicinal properties (Adler et al. 2023; Sgariglia et al. 2010).

Species of the genus *Melipona* are also highly valued by meliponiculturists for the quantity and quality of their honey (Quezada-Euán et al. 2018). *M. quadrifasciata anthidioides* has a more restricted distribution than *T. angustula*, occurring in the southern and southeastern regions of Brazil, Goiás, Mato Grosso do Sul, and much of the northeastern region (from Bahia to Paraíba) (Menezes et al. 2023). This species is also found in southeastern Paraguay and the province of Misiones, Argentina (Filho, 2008). In the latter

Table 2. Socioeconomic characteristics of the meliponiculturists interviewed in the state of Rio de Janeiro, Brazil (n = 43), used in the analyses as categorical and continuous variables. Descriptive statistics for the continuous variables include minimum and maximum values, arithmetic means, and standard deviations. *The age variable was not included in the statistical analyses.

Categorical Variables			
Variables	Category	n	Percentage (%)
Marital status	Single/Divorced	11	25.58
	Married	32	74.42
Location	Urban	28	65.11
	Rural	15	34.89
Levels of involvement in meliponiculture	Primary occupation	7	16.27
	Secondary occupation	22	51.17
	Hobby	14	32.56
Education level	Elementary School (incomplete or complete)	5	11.62
	High School (incomplete or complete)	16	37.22
	Higher Education (incomplete or complete)	22	51.16

Continuous Variables				
Variables	Minimum	Maximum	Mean	Standard deviation
*Age	22	84	45.44	12.53
Number of products	0	6	2.20	1.58
Years of experience	5 months	44	9.04	8.51
Number of managed species	3	19	8.48	3.89

Table 3. Summary of the Generalized Linear Model for the influence of years of experience, education, marital status and number of products extracted from bees on the number of stingless bee species managed by meliponiculturists interviewed in the state of Rio de Janeiro, Brazil.

Number of stingless bee species managed (AIC: 233.15)				
Variation sources	**Estimate**	**Std Error**	**z value**	**p**
Intercept	2.701628	0.272193	9.925	0.0001
Years of experience	0.016487	0.005803	2.841	0.00449**
Education level	-0.141612	0.073426	-1.929	0.05377*
Marital status	0.303060	0.143570	-2.111	0.03478*
Number of products	-0.005836	0.035992	-0.162	0.87119

region, *M. quadrifasciata anthidioides* received a high number of citations in a study conducted with the local population (Zamudio and Hilgert, 2012). In Mexico, the propolis of this species has antifungal properties (Rocha et al. 2024), and its honey exhibits antibacterial effects (Silva et al. 2022).

The species *M. mondury* has an even more restricted distribution than the two species mentioned above, occurring in southeastern Brazil, Bahia, and most of the southern region of Brazil, except for Rio Grande do Sul (Menezes et al. 2023). In addition to being produced in large quantities, the honey of *M. mondury* has medicinal properties (Santos et al. 2017; Viana et al. 2015). However, to the best of our knowledge, this species has not been recorded in any published ethnobiological inventory to date, underscoring the importance of our study and highlighting the need for further research efforts to document local knowledge of stingless bees.

Links between managed stingless bee species and preference criteria

Our first hypothesis was corroborated, as our results demonstrated that the most managed stingless bees are also the most preferred, indicating that respondents select species that are culturally most relevant to them. This pattern aligns with previous stud-

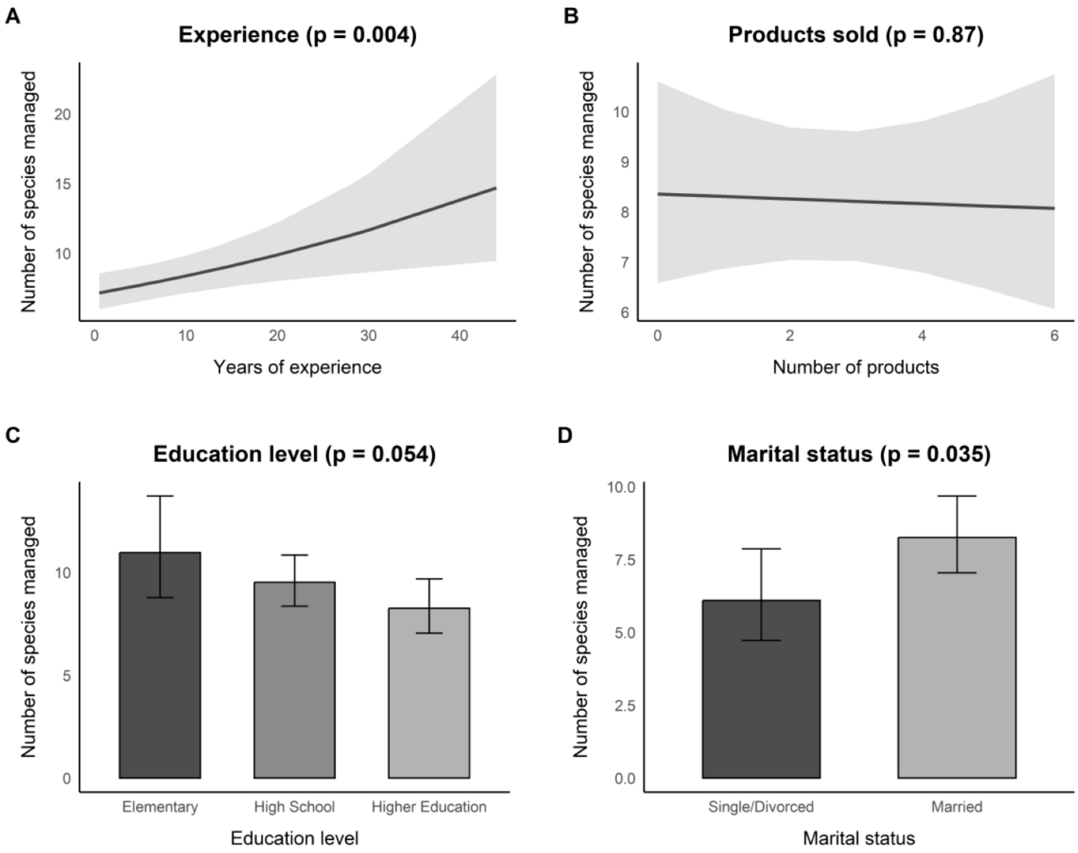

Figure 3. Effect of years of experience (A), number of products sold (B), education level (C), and marital status (D) on the number of stingless bee species managed by meliponiculturists interviewed in the state of Rio de Janeiro, Brazil (95% confidence interval, n=43).

ies highlighting the influence of local knowledge in the selection of species for management (Carvalho et al., 2018; Reyes-González et al. 2014) and may contribute to targeting conservation strategies toward the most used species and those under the greatest pressure from use.

We emphasize the relevance of extracted products, ease of management, and behavior as the primary motivators for meliponiculturists' decisions regarding which species to prioritize in their colonies. The fact that aesthetic and financial criteria received fewer mentions suggests that interviewees prioritize more practical and productive aspects when selecting the most important bees for their colonies. Productivity and behavior were also the most prominent criteria in the choice of stingless bee species for capture by residents of a rural community in northeastern Brazil (Carvalho et al. 2018). In that study, productivity was not linked to financial considerations but rather to subsistence and local economy, as honey did not represent a significant source of income but was an essential part of local livelihoods. In our study, we chose to separate the categories "products" and "financial," as the criteria mentioned by interviewees for these two categories did not necessarily overlap. A similar result was observed in Mexico, where the most important stingless bee species were those whose products were preferred by local experts (Reyes-González et al., 2014). The expression of economic-financial criteria in the preference for bee species appears to be more common among beekeepers than among meliponiculturists (Carvalho et al. 2018), as observed in a study conducted in Ethiopia using *A. mellifera* and its subspecies as a model (Tilahun et al. 2016). In addition to not being a significant criterion for determining species preference, the financial aspect did not prove fundamental in influencing the diversity of stingless bee species managed, as the number of products marketed had no significant effect on the number of species managed by the interviewed meliponiculturists. Extracting and commercializing more products does not necessarily lead to greater species diversification. Instead, factors such as experience, marital status, and lower education levels were significant in

Table 4. Stingless bee species preferred by meliponiculturists interviewed in the state of Rio de Janeiro, Brazil, showing preference categories and the number of citations. AES=aesthetics; BEH=behavior; PRO=products; MAN=management; FIN=financial; CONS=conservation.

	Preference categories						
Species	**AES**	**BEH**	**PRO**	**MAN**	**FIN**	**CONS**	**Total**
Melipona mondury (Uruçu amarela/Bugia)	3	5	8	6	2	3	27
Melipona quadrifasciata anthidioides (Mandaçaia – MQA)	1	3	2	7	1	3	17
Tetragonisca angustula (Jataí)	1	4	2	3	1	2	13
Melipona bicolor (Guaraipo)	2	2	2	1	0	1	8
Melipona compressipes (Tiúba)	1	0	1	1	0	0	3
Melipona marginata carioca (Manduri amarela/ Manduri carioca)	0	1	1	1	0	0	3
Plebeia lucii (Luci)	1	0	0	1	0	0	2
Cephalotrigona capitata (Mombucão)	0	0	1	1	0	0	2
Melipona scutellaris (Uruçu nordestina)	0	1	1	0	0	0	2
Friesella schrottkyi (Mirim preguiça)	1	0	0	0	0	0	1

our model. Thus, our second research hypothesis was partially corroborated. This result suggests that more experienced meliponiculturists diversify their management over time, possibly due to the acquisition of greater technical and practical knowledge about different species. This finding is consistent with research showing that experience is a determining factor not only for the success of stingless management (Jaffé et al. 2015) but also for the management of other components of biodiversity (Campos et al. 2018; Silva et al. 2019).

Socioeconomic and regional factors associated with the diversity of managed stingless bee species

The relationship between marriage and increased knowledge (or diversity of managed species, as in our study) may be related to the fact that married meliponiculturists often have greater assistance in managing and handling different bee species, which could contribute to maintaining a larger number of species in their apiaries. Marriage has been shown to motivate individuals to engage in beekeeping, as observed by Andaregie and Astatkie (2021) in a rural community in Ghana. Regarding education, some studies suggest that formal education can interfere with knowledge and use of natural resources, as time spent in school or university may reduce time spent interacting with and learning about biodiversity (Medeiros et al. 2012). For example, Santos et al. (2020) observed that formal education did not significantly affect knowledge about bird diversity in the Brazilian semiarid region; however, a trend was noted linking higher education levels to a lower number of species named. A similar pattern was found by Souza et al. (2024), who identified a negative relationship between education level and the total number of mammals mentioned by residents of a rural community in the same semiarid region.

We did not observe significant differences in the number of species managed among interviewees with different levels of involvement in meliponiculture, which was unexpected. It was hypothesized that individuals with meliponiculture as their primary occupation would spend more time caring for bees, leading to greater knowledge and a higher diversity of managed species. However, this result suggests that those who practice meliponiculture as a hobby may be equally committed to the activity, achieving levels of knowledge and species diversity comparable to those for whom it is their main occupation. The growing awareness of the importance of stingless bee conservation may be fostering a more homogeneous approach among meliponiculturists, regardless of their location or level of involvement in the activity.

The fact that meliponiculturists in rural regions did not demonstrate greater versatility in their knowledge of bees was also unexpected. Residents of rural areas typically have greater contact with nature, which is often associated with higher levels of local ecological knowledge (Beltrán-Rodríguez et al. 2014; Reyes-Garcia et al. 2007) and, consequently, a greater diversity of managed species. However, urban environments can also support high plant diversity due to the presence of both native and exotic species used in urban landscaping (Vossler, 2019). This abundance of floral resources can attract a wide variety of bees, potentially resulting in a greater diversity of species managed by meliponiculturists in urban areas.

CONCLUSION

Our research demonstrated that the selection and preference of stingless bee species managed by meliponiculturists in the state of Rio de Janeiro are influenced by their cultural importance, ease of management, and productivity. The most managed species were also the most preferred, reinforcing the influence of local knowledge in the choice of bees for breeding. This pattern suggests that conservation strategies may be more effective when aligned with species of greater cultural and economic relevance to meliponiculturists.

Our results indicated that longer experience in meliponiculture, being married, and having a lower level of education played central roles in the diversification of managed species. On the other hand, the level of involvement in meliponiculture and the location (urban or rural) did not significantly influence the diversity of managed species, suggesting that knowledge about stingless bees is not restricted to specific groups or environments. The urban environment also proved to be important for the breeding of these insects.

The three most managed and preferred stingless bee species (*Tetragonisca angustula*, *Melipona quadrifasciata anthidioides*, and *Melipona mondury*) occur naturally in the state of Rio de Janeiro and the Atlantic Forest biome. However, their high cultural and economic importance may indicate significant pressure on their populations, particularly for *M. mondury*, which has a more restricted distribution. The breeding of bees from other biomes, as evidenced in our research, should also be carefully considered, as little is known about the potential competition between these species and those native to the Atlantic Forest biome. Thus, while meliponiculture promotes conservation actions, the presence of species from other biomes should be monitored to avoid potential ecological impacts.

While this study provides important insights into the management and preference of stingless bee species in the state of Rio de Janeiro, it also presents some limitations. First, although we covered a wide range of regions within the state, our sample may not capture the full diversity of practices and knowledge across all meliponiculturists in Rio de Janeiro, particularly in cities or regions where meliponiculture is less common or less well-known. Second, although our findings suggest the presence and management of non-native stingless bee species, this ecological concern was addressed only superficially. While this observation raises important issues, such as the potential introduction of non-native species and competition with native stingless bees, it was not an explicit objective of the study and should therefore be interpreted with caution. This limitation highlights the need for complementary ecological studies to assess the potential impacts of managing species outside their native biogeographic ranges. Future research should also explore strategies to mitigate these impacts and strengthen the conservation of stingless bees in Brazil. Additionally, we recommend further investigation into the relationships between local ecological knowledge, resource availability, and species preferences across diverse socioeconomic and environmental contexts. Such studies could contribute to the development of more sustainable strategies for the management and conservation of stingless bees.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONTRIBUTION STATEMENT

Conceived of the presented idea: JLAC, ASM, VAA. Carried out the experiment: JLAC, ASM, VAA. Carried out the data analysis: JLAC. Wrote the first draft of the manuscript: JLAC. Review and final write of the manuscript: ASM, VAA. Supervision: VAA.

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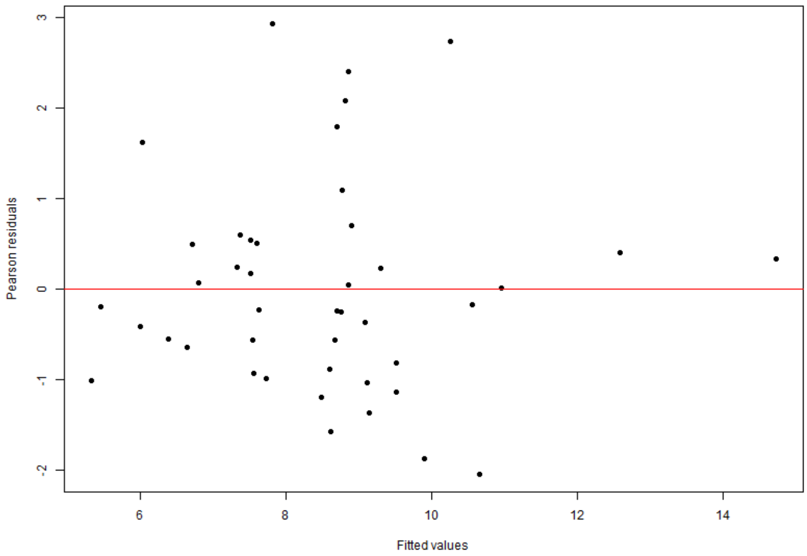
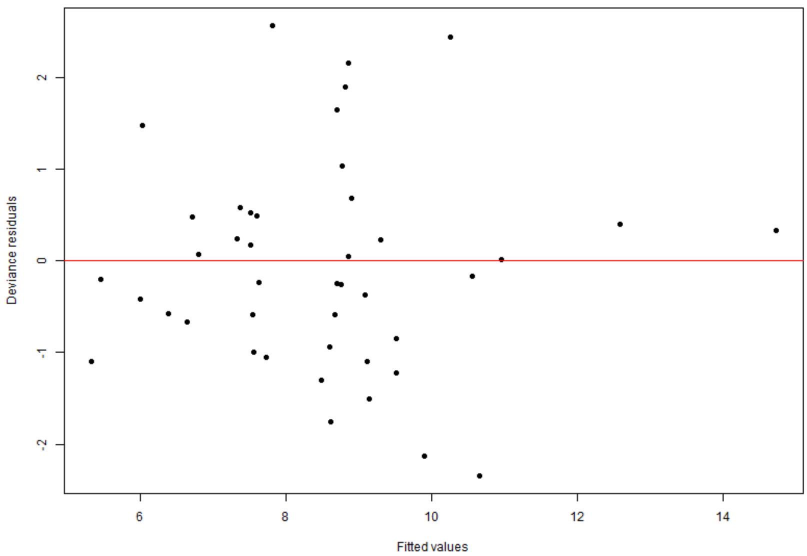
Additional Files

1. Residual Diagnostics

We evaluated the Pearson (Add File 1) and deviance residuals (Add File 2) to verify model assumptions and potential patterns. Both residual types were plotted against the fitted values. No strong patterns or signs of heteroscedasticity were observed, supporting the adequacy of model fit.



Add File 1. Pearson Residuals vs Fitted Values.



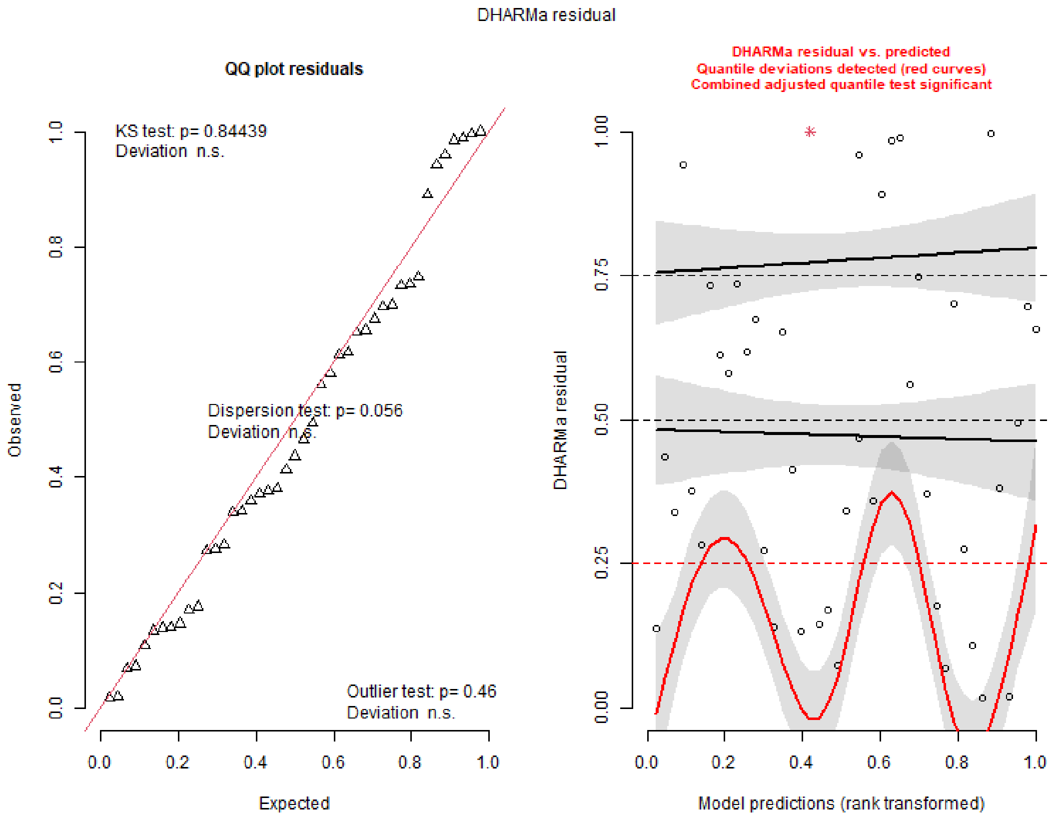
Add File 2. Deviance Residuals vs Fitted Values.

2. Overdispersion Check

The dispersion parameter was calculated as the ratio between the residual deviance and the residual degrees of freedom. The result was 1.46, suggesting no strong evidence of overdispersion. Nevertheless, a quasi-Poisson model was also fitted for robustness, confirming similar significance patterns.

3. Homogeneity of Variance

The DHARMa package was used to simulate and plot scaled residuals. The resulting diagnostic plots indicated no violation of the assumptions of homogeneity, with simulated residuals centered around zero and uniformly distributed (Add File 3).



Add File 3. DHARma residual for homogeneity of variance diagnostics.

4. Model Comparison

We compared the full model to a nested model excluding the 'produtos' variable using AIC and a likelihood ratio test. The full model had a lower AIC (233.15) compared to the reduced model (AIC: X), and the likelihood ratio test indicated that the full model significantly improved the fit ($p < 0.05$).

All diagnostic procedures were performed using R including base functions and the DHARMa package.