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Integrated Knowledge Systems: Ethnotaxonomy and Alpha Taxonomy of Stingless Bees (Hymenoptera: Apidae: Meliponini) in an Amazon-Cerrado Ecotone in Northern Brazil

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Abstract

The articulation between traditional knowledge and scientific understanding has proven essential for the study and conservation of biodiversity, particularly in regions with high biological and cultural diversity. This study aimed to investigate the diversity of stingless bees in the municipality of Araguaína, Tocantins, Brazil, located in an ecotone between the Cerrado and Amazon biomes, through the integration of ethnotaxonomy and alpha taxonomy. We hypothesized that combining these knowledge systems enhances the accuracy and scope of biological inventories. A mixed qualitative and quantitative approach was adopted, with sampling conducted in both natural habitats and meliponiculture systems using scent traps, entomological nets, and collections in managed hives. A total of 103 specimens were collected, distributed across 30 species and 14 genera, surpassing previously recorded diversity for the region. Empirical identification by stingless bee beekeepers – based on morphological traits, behavioral patterns, and nest entrance structures – achieved 61.1% accuracy when compared to formal taxonomic identification. This correspondence highlights the value of traditional knowledge in species classification. The presence of species associated with distinct environments reflects the influence of ecological heterogeneity in the ecotone on faunal composition. The results support the initial hypothesis and demonstrate that the integrated approach offers a more comprehensive view of local biodiversity. Additionally, the findings contribute to sustainable management practices and conservation strategies, reinforcing the importance of interdisciplinary and participatory approaches to pollinator preservation.

Introduction

The integration of scientific knowledge and traditional ecological knowledge represents a strategic approach to biodiversity research and conservation, particularly in contexts of high biological and cultural diversity. This integrative framework broadens and enriches our understanding of biodiversity by incorporating morphological, ecological, and cultural dimensions (Silva, 2015).

Alpha taxonomy, formalized in the 18th century by Linnaeus, provides a biological classification system based on morphological and phylogenetic characters (Domenico, 2012). In contrast, ethnotaxonomy, systematized from the mid-20th century onward, recognizes traditional knowledge as a legitimate and valuable source for the classification of organisms, with significant contributions from scholars such as Harold Conklin and Darrell Posey (Posey, 1987; Berlin, 1992). Alpha taxonomy encompasses the formal processes of species description,

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identification, and classification, whereas ethnotaxonomy refers to classification systems socially and culturally constructed by local communities. While methodologically distinct, these approaches are complementary and, when integrated, offer a more comprehensive and context-sensitive perspective on biological diversity.

An integrated approach combining alpha taxonomy and ethnotaxonomy can be particularly effective in deepening our understanding of species diversity in ecotonal regions such as Araguaína, Tocantins (Mendes, 2021), where taxa from both the Amazon and Cerrado biomes co-occur. In this context, stingless bees (Meliponini) represent an ideal model group for such integration, as they allow the convergence of scientific data, focused on morphology and systematics, with cultural dimensions embodied in the empirical knowledge passed down through generations of stingless bee beekeepers.

According to Costa-Neto (2016), an earlier survey based solely on ethnotaxonomic methods recorded 10 species of stingless bees in the municipality, a figure likely underestimated given the ecological complexity of the ecotone. Therefore, studies employing an integrated methodological approach can significantly enhance the accuracy and comprehensiveness of local biodiversity assessments (Zamudio, 2022; Albuquerque et al., 2014).

Stingless bees (Hymenoptera: Apidae: Meliponini) are eusocial insects characterized by a functionally reduced sting and simplified wing venation (Silveira et al., 2002; Michener, 2007). These bees are essential pollinators of both native and cultivated plants in tropical and subtropical ecosystems (Imperatriz-Fonseca, 2010). However, their ecological significance extends beyond pollination. Recent studies have highlighted their roles as bioindicators of environmental quality (Barbosa et al., 2017), as well as contributors to the maintenance of plant and animal biodiversity and to ecological resilience in the face of environmental disturbances (Garibaldi et al., 2013). In addition to their ecological roles, stingless bees hold substantial cultural and socioeconomic value, exemplified by meliponiculture, a practice dating back to Indigenous peoples of South America and now widely adopted throughout Brazil (Villas-Boas, 2012).

In this context, ethnobiological studies of stingless bees are critical, as they bridge scientific inquiry – focused on species diversity and systematics – with cultural dimensions that value and preserve traditional knowledge. This integrative approach supports both conservation efforts and the sustainable use of these key pollinators.

This study aimed to investigate and compare the effectiveness of ethnotaxonomic identification relative to alpha taxonomy for stingless bee species in a Cerrado–Amazon ecotone in northern Brazil. Furthermore, it sought to contribute to a more comprehensive understanding of stingless bee diversity in this transitional zone. The main hypotheses tested were: (i) the regional diversity of stingless bees is greater than previously reported, and (ii) there is a meaningful correspondence between local ethnotaxonomic classifications and formal scientific taxonomy.

Methods

Methodological approach

This study employed a qualitative-quantitative approach by integrating the documentation of traditional knowledge and local ethnotaxonomy with the formal taxonomic assessment of species richness. It is classified as exploratory and descriptive, aiming to identify and characterize stingless bee species (Meliponini) occurring in both natural habitats and meliponiculture systems in the municipality of Araguaína (Gil, 2002).

Study area

The research was conducted in Araguaína, a municipality located in the northern region of the state of Tocantins, Brazil, situated within an ecotonal zone between the Cerrado and Amazon biomes. Araguaína spans a territorial area of 4,004.65 km², of which only 27.94% remains covered by native vegetation (Silva, 2020). Intensive agricultural and livestock activities, along with the widespread use of agrochemicals (Feltrin, 2021), underscore the ecological significance of the region for evaluating pollinator biodiversity.

Field data were collected from six meliponiculture systems (M1-M6) and five sampling sites (P1-5) (Figure 1), strategically selected to represent urban and peri-urban environments with varying degrees of anthropogenic disturbance and the presence of vegetation fragments. The selection of these locations aimed to encompass the range of habitat types present within this ecological transition zone, thereby enabling a more representative sampling of the local bee fauna.

Specimen collection

Specimen collection was conducted from April to October 2024, employing three complementary methods: passive trapping with scent-baited traps, active netting, and sampling in local meliponiculture systems.

Passive trapping: Three scent-baited traps were installed at each of the five sampling sites, totaling 15 traps. Each trap was constructed using a PET bottle containing cotton soaked in attractive scents and 50 mL of 70% ethanol at the bottom, which served as a preservative to prevent decomposition of captured specimens. Since the number of available scent types (lavender, Sicilian lemon, orange blossom, eucalyptus, and propolis extract) exceeded the number of traps per site, three scents were randomly selected for each site to ensure variation among locations. At each site, traps were spaced 50 meters apart and placed at a height of 1.5 meters from the ground. The traps were inspected biweekly, between 06:00 and 12:00, for maintenance, replenishment of

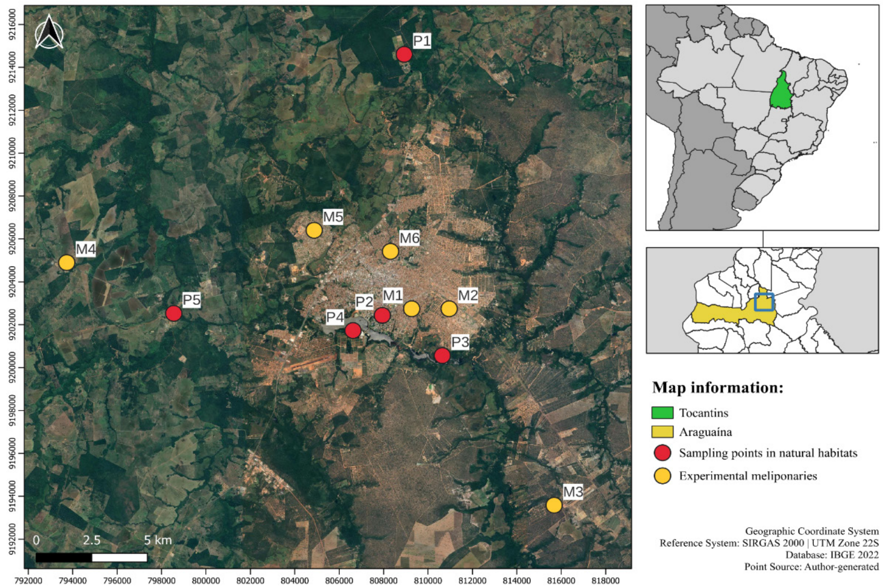

Fig 1. Aerial map of the municipality of Araguaína, Tocantins, Brazil, and surrounding areas showing the five sampling points in natural habitats and the six meliponiculture systems surveyed for stingless bees.

attractants, and collection of trapped bees. This method was adapted from Rebêlo & Garófalo (1991), originally developed for capturing males of Euglossini, but here modified for Meliponini by altering the attractants to those listed above.

Active netting: Active collections were conducted using entomological nets between 06:00 and 12:00, coinciding with peak bee foraging activity. At each of the five sampling points, we followed a linear transect of approximately 180 meters, sampling for about one hour, capturing individuals in flight or visiting flowers. This protocol aligns with standardized methods for sampling bee diversity (Leone et al., 2022). In addition to the primary transects, we also opportunistically sampled in surrounding areas to increase representativeness and detect species that may not be attracted to the passive traps.

Sampling in meliponiculture systems: We conducted visits to six local stingless bee beekeepers. At each meliponary, we collected specimens from the colonies identified by the stingless bee beekeepers themselves.

All collected specimens were placed in 2 mL plastic microtubes and transported to the Biological Collections Laboratory at the Universidade Federal do Norte do Tocantins (UFNT). There, we performed sorting, mounting, and specimen preparation for taxonomic identification. Species were identified using published identification keys (*e.g.*, Schwarz, 1932; Moure & Kerr, 1950; Pedro & Camargo, 2003; Rasmussen & Gonzalez, 2017; Ribeiro et al., 2024) and through comparisons with reference specimens previously identified by experts and deposited at the Instituto Nacional de Pesquisas da Amazônia (INPA). Voucher specimens are deposited in the Terrestrial Insect Collection of UFNT, housed in the Biological Collections Laboratory and under institutional curation.

Ethnotaxonomic identification

The ethnotaxonomic component of this study involved accompanying stingless bee beekeepers during the identification of stingless bee species present in their managed colonies or in nearby wild colonies located in natural habitats adjacent to meliponiculture systems. Each stingless bee beekeeper identified only those species they already managed, using their own criteria such as coloration, body size, and behavioral traits. During these interactions, we asked: *"How do you recognize that this bee belongs to that species?"* Based on their responses, we recorded the criteria used to name and distinguish species. These observations were recorded in real time and later compared with formal taxonomic identifications. It is important to emphasize that no questionnaires, recordings, or personal data were collected; the data were limited to spontaneous observations of the identification process.

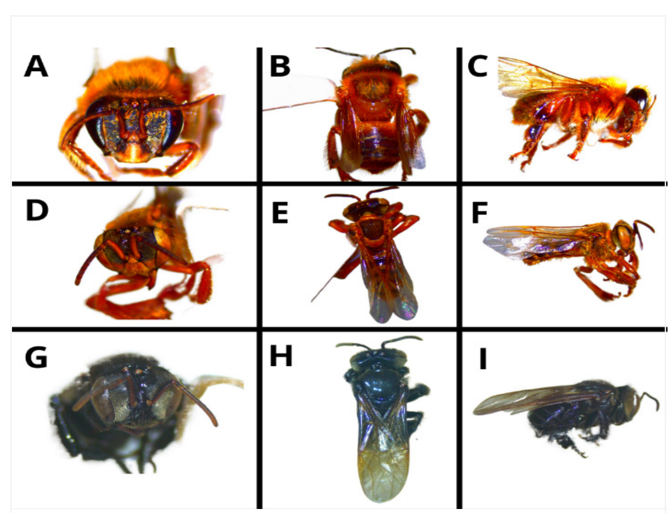

Fig 2. Photographs of Meliponini species submitted for taxonomic confirmation. A, D, G – Frontal view of the face; B, E, H – Dorsal view of the body; C, F, I – Lateral view of the body. A, B, C – *Melipona* (*Michmelia*) *flavolineata* Friese, 1900; D, E, F – *Tetragona dorsalis* (Smith, 1854); G, H, I – *Trigona amazonensis* (Ducke, 1916).

Data analysis

Data analysis consisted of comparing the ethnotaxonomic identifications provided by stingless bee beekeepers with the formal taxonomic identifications carried out by one of the authors affiliated with INPA, based on images of the collected specimens. For the quantitative analysis, we assessed species richness in both natural habitats and meliponiculture systems. Data were tabulated to include the number of individuals, folk (vernacular) names, and occurrence sites (Silveira et al., 2002; Michener, 2007). We evaluated the correspondence between the ethnotaxonomic and scientific classification systems, following the framework proposed by Posey (1987), which underscores the value of traditional knowledge in species identification. The percentage of agreement between the two systems was calculated to assess the accuracy of traditional knowledge relative to scientific taxonomy, using a methodology similar to that described by Albuquerque et al. (2014).

Results

A total of 103 stingless bee specimens were recorded in the municipality of Araguaína, Tocantins, representing 14 genera and 30 species and morphospecies (Table 1). Of these, 66 individuals were collected from meliponiculture systems and 37 from natural habitats. Seventeen species were found exclusively in meliponiculture systems, 11 exclusively in natural habitats, and two occurred in both environments.

The genus *Trigona* was the most abundant, with six species recorded: *Trigona amazonensis*, *T. braueri*, *T. pallens*, *T. dallatorreana*, *T. spinipes*, and one unidentified morphospecies referred to as *Trigona* sp.1. The most frequently collected species was *T. spinipes*, with 12 individuals.

For specimens with uncertain identity, we assigned provisional designations, classifying seven as morphotypes “sp.” (from the Latin species, indicating an unidentified species within a known genus), two as “aff.” (abbreviation of *affinis*, used to indicate a species similar to another but not definitively

Table 1. Records of stingless bee species identified through alpha taxonomy in the municipality of Araguaína, Tocantins, Brazil.

Species	Folk name	n
Melipona (Michmelia) flavolineata Friese, 1900	Uruçu-amarela	6
Melipona (*Melikerria*) *fasciculata* Smith, 1854	Tiúba	6
Melipona (Michmelia) seminigra pernigra Moure & Kerr, 1950	Uruçu-boca-de-renda, uruçu-preta	8
Plebeia sp.		2
Plebeia sp.1		1
Plebeia sp.2		2
Trigona sp.1		3
Geotrigona sp.1		2
Partamona sp.1		1
Frieseomelitta aff. *varia*		4
Frieseomelitta longipes (Smith, 1854)	Marmelada	2
Frieseomelitta cf. *varia*		2
Frieseomelitta silvestrii (Friese, 1902)	Mocinha-preta	2
Leurotrigona aff. *muelleri*		2
Nannotrigona dutrae (Friese, 1901)		2
Nannotrigona punctata (Smith, 1854)	Iraí	2
Oxytrigona mulfordi (Schwarz, 1948)	Tataira	3
Partamona ailyae Camargo, 1980	Cupira	6
Scaura longula (Lepeletier, 1836)	Jataí-preta	2
Scaptotrigona depilis (Moure, 1942)	Tubiba/Canudo	4
Scaptotrigona aff. *depilis*		4
Tetragonisca angustula (Latreille, 1811)	Jatai	8
Tetragona dorsalis (Smith, 1854)	Borá-bico-de-vidro	4
Trigona amazonensis (Ducke, 1916)	Xupé-grande	2
Trigona braueri Friese, 1900	Abelha-cachorro	4
Trigona pallens (Fabricius, 1798)	Olho-de-vidro	2
Trigona dallatorreana Friese, 1900	Arapuá-vermelha	2
Trigona spinipes (Fabricius, 1793)	Arapuá	12
Tetragona mourei Nogueira, 2022		3
Lestrimelitta sp.		not collected
Total: 30 species		**Total:** 103 specimens

n = number of specimens collected.

identified), and one as "cf." (from *confer*, meaning "compare with", used when a tentative identification is suggested based on similarity to a known species). Additionally, we recorded the presence of a colony belonging to the genus *Lestrimelitta*; however, it was not possible to collect specimens for species-level identification.

During visits to meliponaries, we observed that stingless bee beekeepers employ identification criteria based on external morphological traits (such as body size and coloration), typical behaviors (e.g., defensiveness), and the architecture of the nest entrance. These criteria are widely recognized in the meliponiculture literature. According to Zamudio (2022), features such as the shape of the nest entrance and coloration patterns are essential for distinguishing between species. Similarly, Souza (2009) emphasizes that the structure of the entrance tunnel, often built with mud, cerumen, feces, or other materials, serves as an important diagnostic trait and is often associated with the defensive behavior of the colony.

These observations were recorded in a descriptive framework (Table 2) and later compared with formal taxonomic identifications, enabling an assessment of the accuracy of traditional knowledge in species recognition.

Table 2. Ethnotaxonomic identification criteria based on external morphology, behavioral traits, and nest entrance characteristics used by stingless bee beekeepers to distinguish stingless bee species.

Identification Criteria	Description
Morphology	
Size	Stingless bees exhibit distinct size ranges according to species, facilitating ethnotaxonomic identification by stingless bee beekeepers. Large-bodied species such as *Melipona flavolineata* ("Uruçu-amarela") and *Melipona fasciculata* ("Tiúba") measure between 9-12 mm. Medium-sized species like *Tetragonisca angustula* ("Jataí"), *Trigona pallens* ("Olho-de-vidro"), and *Frieseomelitta longipes* ("Marmelada") range from 4-7 mm. The smallest species, such as *Leurotrigona muelleri* ("Lambe-olhos"), measure around 2.5 mm. This size variation is a key trait in local empirical identification.
Color	Color variation is a key element in folk identification. For example, *Melipona flavolineata* ("Uruçu-amarela") is predominantly yellow, whereas *Melipona seminigra pernigra* ("Uruçu-preta") is mostly black with pale setae on the mesepisternum and amber tones on the anterior metasomal segments.
Behavior	
Docility	Non-aggressive behavior is commonly observed in species such as *Melipona fasciculata* ("Tiúba"), which retreat into the nest upon human approach. Their docility facilitates handling and makes them suitable for beginner stingless bee beekeepers and urban beekeeping. *M. fasciculata* is considered one of the most docile species in the Amazon (Venturieri, 2008).
Invasiveness	Certain cleptobiotic species, such as *Lestrimelitta* spp. ("Abelha-limão"), invade other native bee colonies to steal food and wax. This conspicuous behavior enables easy identification based on interspecific interactions.
Defensiveness	Aggressive behavior is also used as a diagnostic trait. For instance, *Trigona spinipes* ("Arapuá") can bite and entangle in human hair, while *Oxytrigona tataira* ("Tataíra") secretes a caustic fluid that causes irritation or burns. These behaviors discourage stingless bee beekeepers from maintaining such species (Nogueira-Neto, 1997).
Nest Entrance Features	
Nest entrance structure and architecture	Some species build conspicuous resin and mud nest entrances. For example, *Melipona seminigra pernigra* ("Uruçu-preta") constructs a trumpet-shaped tube with ornate resinous borders. Others, like *Oxytrigona tataira*, lack entrance structures and use simple crevices. These structural traits – such as tube length, resin thickness, and coloration – are considered important visual cues for species distinction (Costa, 2019).

Stingless bee beekeepers empirically recognized a total of 25 stingless bee species, using the identification criteria outlined in Table 2. Of these, seven species (28%) were designated only as aff. or sp., which prevented accuracy assessment for these cases.

Considering only the 18 species for which evaluation was possible, 11 species (61.1%) were correctly identified by the stingless bee beekeepers, while 7 species (38.9%) were misidentified when compared to the formal taxonomic diagnoses (Table 3).

Table 3. Comparison between ethnotaxonomic identifications made by meliponiculturists and formal taxonomic identifications, highlighting the accuracy and names attributed in each approach.

Ethnotaxonomy			Alpha taxonomy	
Species	**Folk name**	**Accuracy**	**Verified species**	**Folk name**
Melipona (Michmelia) flavolineata Friese, 1900	Uruçu-amarelo	Correct	-	-
Melipona (Melikerria) fasciculata Smith, 1854	Tiúba	Correct	-	-
Melipona (Michmelia) seminigra pernigra Moure & Kerr, 1950	Uruçu-preta	Correct	-	-
Scaura longula (Lepeletier, 1836)	Jataí-Negra	Correct	-	-
Frieseomelitta silvestrii (Friese, 1902)	Mocinha-preta	Correct	-	-
Frieseomelitta flavicornis (Fabricius, 1798)	Moça-branca	Undetermined	*Frieseomelitta* aff. *varia*	-
Partamona helleri (Friese, 1900)	Boca-de-sapo	Incorrect	*Partamona ailyae* Camargo, 1980	Cupira
Tetragonisca angustula (Latreille, 1811)	Jataí	Correct	-	-
Tetragona clavipes (Fabricius, 1804)	Borá	Incorrect	*Tetragona dorsalis* Smith, 1854	Borá-bico-de-vidro
Scaptotrigona tubiba (Smith, 1863)	Tubi-mansa	Incorrect	*Scaptotrigona depilis* (Moure, 1942)	Tubiba
Plebeia flavocincta (Cockerell, 1912)	Jati	Undetermined	*Plebeia* sp.	-
Trigona spinipes (Fabricius, 1793)	Arapuá	Incorrect	*Trigona amazonensis (Ducke, 1916)*	Chupé
Trigona recursa Smith, 1863	Feiticeira	Incorrect	*Trigona braueri* Friese, 1900	Abelha-de-cachorro
Trigona pallens (Fabricius, 1798)	Olho-de-vidro	Correct	-	-
Frieseomelitta longipes (Smith, 1854)	Marmelada	Correct	-	-
Scaptotrigona tubiba (Smith, 1863)	Tubi-bravo	Undetermined	*Scaptotrigona* aff. *depilis*	-
Plebeia droryana (Friese, 1900)	Mirim-droryana	Undetermined	*Plebeia* sp.2	-
Scaptotrigona polysticta Moure, 1950	Bijui	Undetermined	*Scaptotrigona* aff. *depilis*	-
Friesella schrottkyi (Friese, 1900)	Mirim-preguiça	Incorrect	*Nannotrigona punctata* (Smith, 1854)	iraí
Frieseomelitta varia (Lepeletier, 1836)	Manoel-de-abreu	Undetermined	*Frieseomelitta* aff. *varia*	-
Partamona ailyae Camargo, 1980	Cupira	Correct	-	-
Trigona dallatorreana Friese, 1900	Arapua-amarela	Correct	-	-
Nannotrigona punctata (Smith, 1854)	Iraí	Incorrect	*Trigona dallatorreana* Friese, 1900	Arapuá-vermelha/ Arapuá-amarela
Leurotrigona muelleri (Friese, 1900)	Lambe-olhos	Undetermined	*Leurotrigona* aff. *muelleri*	-
Oxytrigona mulfordi (Schwarz, 1948)	Tataíra	Correct	-	-

Discussion

This study documented 30 stingless bee species in the municipality of Araguaína, Tocantins, more than double the ten species previously reported in the region (Costa-Neto, 2016). This marked increase underscores the necessity of broad-scale surveys that include both natural habitats and meliponiculture systems and highlights the ecotonal nature of Araguaína, situated between the Cerrado and Amazon biomes, as a key driver of species richness. The ethnotaxonomic identification accuracy, when compared with alpha taxonomy, reached 61.1%, further supporting the value and validity of stingless bee beekeepers' empirical knowledge. These findings are highly relevant for researchers, practitioners, and conservationists, providing support for sustainable management practices and biodiversity conservation planning (Albuquerque et al., 2014; Berlin, 1992).

Our data revealed 17 species exclusively associated with meliponiculture systems, compared to 11 species restricted to natural habitats. This suggests that well-managed meliponiculture can play a crucial role in sustaining and potentially enhancing local stingless bee diversity, as these systems provide consistent floral resources, nesting shelter, and environmental stability (Venturieri, 2003; Pereira, 2012). Moreover, the observed diversity in meliponaries may derive from both intentional colony introductions and attraction of native species, effectively serving as seedbeds for conservation and species dispersal (Jaffé et al., 2013). Nonetheless, preserving natural habitats remains essential to maintain unmanaged species and complex ecological interactions that managed systems may not replicate.

Both hypotheses formulated at the study's inception were confirmed: (1) Araguaína supports a greater stingless bee diversity than previously recorded, and (2) the integration of ethnotaxonomy with formal taxonomy is both reliable and effective, further demonstrating that traditional ecological knowledge significantly contributes to species identification and management. Potential drivers of the observed diversity include the region's ecotonal geography and habitat heterogeneity – urban interfaces, agriculture, and remnant vegetation – which provide diverse ecological niches suitable for a range of stingless bee species (Nogueira-Neto, 1997; Silveira et al., 2002).

Integrating ethnotaxonomy with alpha taxonomy proved to be a complementary and enriching approach. Ethnotaxonomy provides a practical, rapid, and community-accessible method for species identification, while alpha taxonomy ensures scientific rigor and standardization (Posey, 1987; Zamudio, 2022). We thus propose a combined methodology that merges empirical observations with detailed morphological and taxonomic analyses. This approach directly benefits stingless bee beekeepers by refining managed species identification and improving meliponiculture practices, enhancing faunal inventory efficiency for researchers, and supporting conservation efforts by contextualizing strategies across ecological and cultural dimensions (Albuquerque et al., 2014; Villas-Boas, 2012).

Among the strengths of this study were the novel integration of scientific and traditional methods and the comprehensive sampling across habitat types. However, limitations must be recognized. A relatively small sample size, a limited sampling period, and restricted access to certain areas may have reduced species detection and representativeness (Thomazini & Thomazini, 2000; Silveira, 2010). Additionally, the passive trapping method, originally designed for Euglossini male bees, may not have been fully effective for Meliponini, particularly in natural environments. The experimentally selected attractant essences, which were not based on well-established protocols, may also have reduced trap success.

Several contextual factors likely influenced the results. Collections occurred from April to October, a transitional period between the rainy and dry seasons, which may have affected bee foraging activity and, consequently, species detection (Jaffé et al., 2013). The intense use of agrochemicals in the municipality, the highest in Tocantins (Silva, 2018), as well as habitat fragmentation, may have negatively impacted species abundance and distribution (Mapa, 2023; Feltrin, 2021).

When compared to regional studies such as Costa-Neto (2016) and Barros (2022), our results align with those combining ethnotaxonomy and taxonomy in terms of identification accuracy; yet our species diversity was substantially higher, likely because those studies focused exclusively on meliponiculture and omitted natural habitats. This underlines the importance of considering ecological, methodological, and cultural variation in biodiversity research (Milan, 2017).

These results make a significant contribution to stingless bee conservation by providing updated, comprehensive data on local species diversity. For stingless bee beekeepers, these insights enable more precise species identification and encourage sustainable beekeeping practices tailored to each species' biology. From a conservation standpoint, melding traditional and scientific knowledge supports strategies that incorporate both ecological and cultural factors, vital for maintaining biodiversity and pollination services (Potts et al., 2010; Martini, 2015).

Conclusions

This research highlights the richness and diversity of stingless bees in Araguaína and underscores the importance of combining local ecological knowledge with rigorous scientific taxonomy. The joint application of ethnotaxonomy and alpha taxonomy allowed identification of 30 distinct species and confirmed the value of empirical knowledge held by stingless bee beekeepers as a valid complement to formal science. The survey significantly expanded previous records and fundamentally strengthened the basis for future conservation efforts.

Active participation of stingless bee beekeepers in species identification revealed notable accuracy, particularly through their use of traditional morphological and behavioral traits. This synergy between science and traditional knowledge emphasizes the value of interdisciplinary and participatory approaches in ecological research. Additionally, the coexistence of species in both managed and natural settings demonstrates the resilience and adaptability of stingless bees in ecotonal regions such as northern Tocantins.

In conclusion, recognizing and integrating traditional knowledge with scientific taxonomy is essential for advancing effective conservation and sustainable management of stingless bees. In the face of mounting biodiversity threats, studies like this are crucial for safeguarding pollinators and the vital ecosystem services upon which both natural systems and human communities depend.

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Authors' Contribution

MSA: Conceptualization; methodology; investigation; data curation; writing-original draft; writing-review & editing.
JAS-S: Taxonomic identification; validation; writing-review & editing; translation of the manuscript.
LS: Supervision; writing-review & editing.

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