Essay

Stingless bees (Tribe Meliponini) in Latin American agroecosystems

Natalia Real-Luna[1, 2]
Jaime Ernesto Rivera-Hernández[3]
Graciela Alcántara-Salinas[1]
Geovanna Rojas-Malavasi[4]
Ana Paulina Morales-Vargas[4]
Juan Antonio Pérez-Sato[1§]

[1]Postgraduate College-Cordoba *Campus*. Federal Highway Córdoba-Veracruz km 348, Manuel León, Amatlán de los Reyes, Veracruz, Mexico. (nreal@colpos.mx; alcantara.graciela@colpos.mx). CP. 94953. [2]Doctorate in Natural Sciences for Development-Technological Institute of Costa Rica-National University-State Distance University. Costa Rica. [3]Center for Geographic, Biological and Community Studies SC. Santa Maria Street no. 13, U. Hab. San Roman, Cordoba, Veracruz. (jriverah@geobicom.org). [4]School of Biology-University of Costa Rica. San Jose Costa Rica. Section 2060. (geovanna.rojas@ucr.ac.cr; ana.moralesvargas@ucr.ac.cr).

[§]Corresponding author: pantonio@colpos.mx.

Abstract

Meliponines are important pollinators of wild and cultivated plants in Latin America. In addition, these bees have the characteristics of a bioindicator, information necessary to develop conservation and sustainable management strategies for species of cultural, ecological, and economic importance. The objective of this work is to determine the species of meliponines that pollinate agroecosystems in Latin America and their use as bioindicators, which will serve as the basis for implementing strategies for the conservation and sustainable management of these bees. This research used sources of information related to the meliponines present in Latin America, crops they pollinate and the use of these stingless bees as bioindicators. Forty-six crops pollinated by meliponines in eight countries were recorded, where 17 genera and 54 species were recorded, with Brazil being the country with the highest record with 33 crops. Meliponines contribute directly to the pollination of agroecosystems, improving yield and quality, therefore it is important to establish strategies for conservation of these bees, such as maintaining flower patches that serve as food throughout the year. The protection of stingless bees is necessary because of the importance they have in the pollination service; however, it is also needed to conduct more research on their biology and their use in greenhouses, in addition to their usefulness as bioindicators.

Key words: bioindicators, meliponines, pollinators.

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Meliponines belong to the order Hymenoptera, family Apidae, subfamily Apinae, Tribe Meliponini, are found in tropical and subtropical regions of Africa, Asia, Australia and the Americas, in the latter continent, there is a record of them in Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru and Venezuela; that is, they are present in the tropical region of Latin America (Portuondo and Fernández, 2004; Genaro, 2004; Micherner, 2007; Ayala *et al*., 2013; Genaro and Lóriga, 2018; Aldasoro *et al*., 2021). In the ecological aspect, meliponines contribute to the conservation of germplasm of populations of wild and cultivated plants, since being efficient pollinators, they help with 50% and up to 70% of the reproduction of these plants, many of which serve as food for the human species and other animals, thus contributing to food security and the ecological balance of ecosystems (Alquisira-Ramírez, 2019).

Other aspects to consider about stingless bees is that they have been used as ecological and environmental bioindicators, as they show the effects of environmental changes such as habitat alteration and climate change (Meléndez *et al*., 2015). There is also evidence of the use and cultural value of this tribe in various parts of Mesoamerica, South America and in other parts of the world, not only in terms of their material use, but also in relation to beliefs and traditions (Quezada-Euán *et al*., 2018; Chan-Mutul *et al*., 2019; Bhatta *et al*., 2020; Aldasoro *et al*., 2021). In the present study, the species of meliponines that pollinate agroecosystems in Latin America and their use as bioindicators were determined, which will serve as a basis for implementing strategies for the conservation and sustainable management of these bees.

Meliponines in Latin America

Stingless bees (Meliponini) comprise more than 500 species. The greatest diversity is found in the Neotropical region of the Americas with 417 species (De Menezes, 2014). Table 1 shows the number of meliponine species for which documented records were found for Latin America. Brazil has the highest number of species with 192, followed by Colombia with 129 species.

Table 1. Number of meliponine species documented in Latin America.

Country	No. of species	Reference
Argentina	37	Alvarez and Lucia (2018)
Brazil	192	Costa *et al*. (2018)
Bolivia	12	Ferrufino and Vit (2013)
Colombia	129	Nates-Parra (2001
Costa Rica	60	Aguilar *et al*. (2013)
Cuba	1	Genaro and Lóriga (2018)
Ecuador	89	Vit *et al*. (2017)
Guatemala	33	Enríquez and Ayala (2014)
Mexico	46	Ayala (1999)
Panama	63	Roubik and Moreno (2018)
Venezuela	83	Silva and Franco (2013)

Stingless bees and pollination

The plant-bee interaction is undoubtedly part of an important coevolutionary history, as mentioned by Bloch *et al*. (2017), plants have developed some characteristics to facilitate pollination by bees, such as: the color, aroma and opening of flowers, as well as the production of rewards for pollinators, such as nectar, pollen and resins. These interactions between plants and stingless bees contribute to the pollination of agroecosystems (Kevan and Silva, 2020), which becomes important because between 75 and 84% of cultivated species depend on pollination for fruit and seed production (Meléndez *et al*., 2018; Badillo-Montaño *et al*., 2019).

Among other strategies that bees have, is that some species visit many flowers (polyfloral) such as *Melipona solani* Cockerell, 1912 and *Scaptotrigona mexicana* (Guérin, 1845), other bees have preference for a type of flower (monofloral) such as *Melipona beecheii* (Bennett, 1831; Espinoza-Toledo *et al*., 2018). Also, some species such as *Tetragonisca angustula* Latreille, 1811, *Nannotrigona testaceicornis* Lepeletier, 1836 and *Partamona helleri* (Friese, 1900), use anthropogenic materials as nesting material (Vieira *et al*., 2016). On the other hand, other species nest exclusively in trees or natural substrates, which makes them more vulnerable to ecosystem fragmentation (Lichtenberg *et al*., 2017).

Stingless bees are affected by land use change and agricultural intensification, these being the main causes of the decrease in these pollinators (Thomann *et al*., 2013; Carneiro-Neto *et al*., 2017). On the other hand, bees are susceptible to agrochemicals such as neonicotinoids, permethrin, diazinon, methomyl and organochlorines, which have lethal and sublethal effects on these bees, which can be ingested through nectar, pollen, water or when they collect resins and clays. It is important to carry out actions to prevent damage to these species of importance for agriculture in Latin America (Valdovinos-Núñez *et al*., 2009; De Souza *et al*., 2015; Ruiz-Toledo *et al*., 2018; Cham *et al*., 2019).

Crops pollinated by meliponines in Latin America

Meliponines can be used efficiently in seasonal crops and greenhouses, as they are adapted to regional conditions (Nicodemo *et al*., 2018; Abrol *et al*., 2019). There are reports that 40% of the crops produced in greenhouses require pollinating agents, mainly meliponines. These bees have also been recorded in improving the production, quality, shelf life and commercial value of the seeds of a variety of crops (Rader *et al*., 2016).

Likewise, meliponines are pollinators of open and greenhouse crops (Heard, 1999; Meléndez-Ramírez *et al*., 2002; Slaa *et al*., 2006). In Argentina, Brazil, Colombia, Costa Rica, Cuba, Mexico, Panama and Peru, 17 genera of meliponines are recorded, among them: *Cephalotrigona*, *Frieseomelitta*, *Geotrigona*, *Lestrimelitta*, *Melipona*, *Nannotrigona*, *Oxytrigona*, *Paratrigona*, *Partamona*, *Plebeia*, *Scaptotrigona*, *Scaura*, *Tetragonisca*, *Tetragona*, *Tetragonula*, *Trigona* and *Trigonisca*, resulting in a total of 54 species recorded in Latin America. Brazil has the largest number of species with 22 species, followed by Mexico with 18 and Costa Rica with 16. Regarding the studies that have been carried out on pollination with meliponines, it is recorded that, in Latin America, meliponines pollinate 46 crops. Table 2 presents the number of species and crops pollinated by these bees, Brazil has the highest number of crops with 33, followed by Mexico with 20.

Table 2. Number of meliponine species and the number of pollinated crops in Latin America.

Country	No. of species	No. of crops	Reference
Argentina	2	3	Flores and Sánchez (2010); Flores *et al*. (2015)
Brazil	22	33	Aurelio (2008); Giannini *et al*. (2012, 2015, 2020); Fuzaro *et al*. (2018); Alves *et al*. (2020); Da Silva *et al*. (2020); Nicodemo *et al*. (2013); Malerbo-Souza *et al*. (2020); Malerbo-Souza and Halak (2009); Pardo and Borges (2020); Santos *et al*. (2018).
Colombia	5	2	Botero and Morales (2000); Brieva-Oviedo and Núñez-Avellaneda (2020)
Costa Rica	16	9	Hedstrom (1986); Ricketts (2004)
Cuba	1	2	Fonte *et al*. (2012)
Mexico	18	20	Bonet and Vergara (2016); Delgado-Carrillo *et al*. (2018); Ish-am *et al*. (1999); Grajales-Conesa *et al*. (2013); Quezada-Euán (2009, 2018); Ramírez-Arriaga *et al*. (2018); Rincón-Rabanales *et al*. (2015)
Panama	5	7	Vinícius-Silva *et al*. (2017)
Peru	2	1	Meléndez *et al*. (2018)

The crops in which the largest number of meliponine species was recorded are *Persea americana* Mill. (avocado) with 14 species, *Coffea arabica* L. (coffee) and *Cocos nucifera* L. (coconut) with 11 species, *Psidium guajava* L. (guava) with 10 species, *Capsicum chinense* Jacq. (Habanero pepper) with nine species, *Bixa orellana* L. (achiote) with eight species, *Capsicum annuum* L. (bell pepper) with seven species, *Citrus* sp. (citrus) and *Lycopersicon esculentum* Mill. (tomato) with six species, *Citrullus lanatus* (Thunb.) Matsum. & Nakai (watermelon), *Citrus sinensis* (L.) Osbeck (orange), *Cucumus sativus* L. (cucumber), *Cucurbita moschata* Duchesne (squash) and *Nephelium lappaceum* L. (rambutan) with five species (Figure 1).

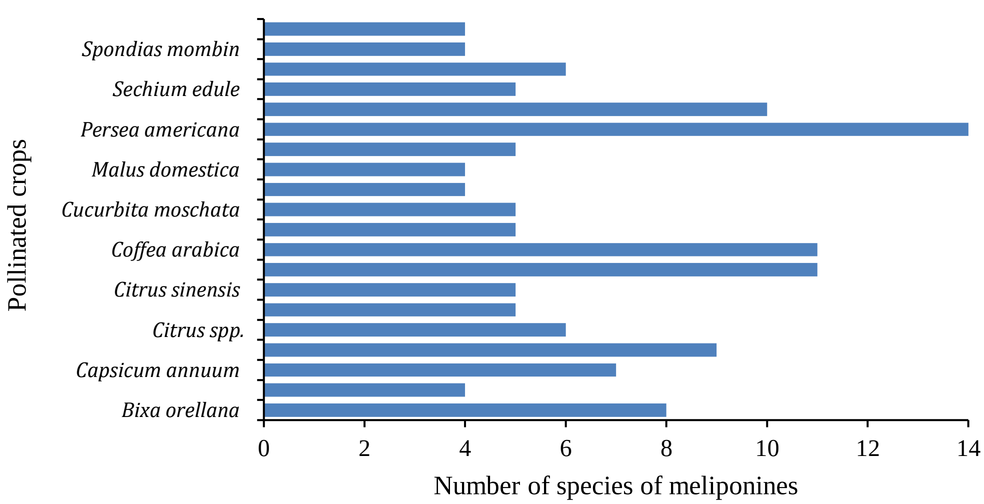

Figure 1. Number of meliponine species that pollinate crops in Latin America.

Meliponine species associated with crops in Latin America

Regarding meliponine species, it was found that *Trigona spinipes* (Fabricius, 1793) is associated with 22 crops, *Tetragonisca angustula* (Latreille, 1811) with 17, *Trigona fulviventris* Guérin-Méneville, 1844 with 11, *Nannotrigona perilampoides* (Cresson, 1878) and *Scaptotrigona mexicana* (Guérin-Méneville, 1844) with 10, *Melipona fasciculata* Smith, 1854 and *Trigona corvina* Cockerell, 1913 with seven, *Frieseomelitta nigra* (Cresson, 1878) and *Partamona bilineata* (Say, 1837) with six and *Melipona beecheii* (Bennet, 1831) with five crops.

Derived from the above, it is evident that stingless bees contribute directly to the pollination of plants in Latin American agroecosystems, also as mentioned by De Menezes (2014); Halinski *et al*. (2018), these bees increase crop yield and improve fruit quality, which is why these bees are considered a socioeconomic resource.

To conserve the diversity of stingless bees that contribute to crop pollination, it is necessary to maintain flower patches close to plantations that serve as food when the crop is not in flowering (Carneiro-Neto *et al*., 2017). Likewise, it is important to guarantee the availability of flower resources during the seasons of the year, this by sowing different crops whose flowering, together, covers the whole year (Vollet-Neto *et al*., 2018).

This can be achieved indirectly by abstaining from the use of herbicides, since a large part of the plants considered weeds function as a food source for bees, especially those with predominant height (Hernández-Villa *et al*., 2020). It is important to note that the use of any type of herbicide or pesticide is strongly harmful to stingless bees and although there are already studies on this topic on *Apis mellifera* and some on meliponines, it is necessary to develop protocols to evaluate the toxic effects of agrochemicals on stingless bees (Lima *et al*., 2016; Cham *et al*., 2019).

In the same way, sites suitable for the nesting of these bees must be maintained near the crops, so that they can move to pollinate them. It is important to consider the impact that crops have on bee populations in terms of their gene pool, since nests are often very separate from others and new hives show less genetic diversity among them (Fonseca *et al*., 2017). Because most new hives depend on the migration of a swarm and material from a mother hive, the isolation or transfer of nests to distant areas leads to a high increase in inbreeding (Vollet-Neto *et al*., 2018). It has been documented that poor genetic diversity in bees can lead to populations not being viable and not withstanding changes in the environment.

A clear example of this is the significant increase in diploid males, which give extra weight for the hive, in addition to reducing the potential size of workers, all this because they originally corresponded to eggs deposited with the intention of generating workers (Vollet-Neto *et al*., 2018). On the other hand, it is important to carry out conservation and restoration strategies for some disturbed areas that serve as a refuge for pollinators when crops are not present and thus protect pollinators (Giannini *et al*., 2017). It has been reported that crops with greater plant diversity offer more suitable environments for pollinators, maintaining good populations and benefiting production (Badillo-Montaño *et al*., 2019).

Particularly, a great advantage that meliponines have in the tropics is that, unlike their temperate zone variants, it seems that those species with relatively more specialized diets tend to adapt better to urban environments (Lichtenberg *et al*., 2017), which implies that more resilient species could potentially be used in crop pollination compared to using another bee tribe.

The stingless bees of the Tribe Meliponini as bioindicators

Bioindicators are a species or a group of species that are used as indirect measures to assess positive or negative changes in an ecosystem (Parmar *et al*., 2016). The characteristics that a bioindicator should have, with emphasis on insecticides, are: a) ease of determining biological impacts and monitoring the synergistic and antagonistic impacts of various contaminants; b) ease of diagnosis at an early stage, as well as the harmful effects of toxins or effects toxic to plants and humans; c) it can be easily assessed, due to prevalence; d) economically viable compared to other more specialized measuring systems; e) high richness, species diversity; f) ease of being observed and monitored; g) the presence or absence provides information on environmental health; h) have ecological fidelity; and i) respond to changes in ecosystem structure or environmental quality (Reyes-Novelo *et al*., 2009; Baldi *et al*., 2014; Meléndez *et al*., 2015; Parmar *et al*., 2016; Nascimento *et al*., 2018).

Stingless bees can be used as ecological and environmental bioindicators because they are affected by changes in the natural environment, such as: habitat alteration and destruction, fragmentation, deforestation, competition with exotic species and climate change (Baldock, 2020), in addition to fulfilling the following characteristics that make them suitable for this purpose, according to Reyes-Novelo *et al*. (2009): 1) The taxonomy of the group is known and stable; that is, species can be reliably identified; 2) the biology and way of life are known; 3) they are important in the structure and functioning of ecosystems; 4) they can be easily observed, captured and handled, without jeopardizing their preservation; 5) the distribution comprises different habitats; 6) they are sensitive to habitat degradation and regeneration to varying degrees; and 7) there are some species of economic importance.

In Latin America, it has been studied how their populations change with the alteration of natural environments, since some species such as those of the genus *Melipona* are very sensitive to deforestation; their presence and density is determined by forest cover, according to a study carried out in Rondônia, Brazil (Brown and Albrecht, 2001). Most species of meliponines nest in cavities, either in trunks or on the ground, and in studies carried out in Colombia, the composition of the species varies depending on the environmental alteration, for example, there are species such as *Tetragonisca angustula* (Latreille, 1811) and *Tetragona perangulata* (Cockerell, 1917) that adapt very well to altered environments, while others are only abundant in secondary or mature forests, such as the different species of *Melipona* (Nates-Parra *et al*., 2008). This evidence supports their potential as indicators of alteration.

Their abundance and the survival of stingless bee colonies have been shown to respond to both this environmental alteration and pesticide exposure (Baldock, 2020). Acute exposure to pesticides such as imidacloprid, spinosad and copper sulfate directly or indirectly affect their survival and chronic exposure causes very severe malformations in larval development that cause death, especially in the species *Partamona helleri* (Friese, 1900) and *Scaptotrigona xantorica* (Moure, 1950) in the long term (Araujo *et al*., 2019; Botina *et al*., 2020).

A similar effect was observed with chlorpyrifos in the species *Plebeia droyana* (Holmberg, 1903), in which, in addition to the effects already mentioned, a reversal of queens to workers occurred, which could affect by preventing the formation of swarms (Sponsler *et al*., 2019). Therefore, the abundance of hives per area and their diversity could be correlated, in addition to the physical alteration of the habitat, with exposure to pesticides and other toxic substances. Additionally, stingless bees and other pollinators must be considered in the regulation of the diversity of agricultural products, since only the honeybee is used for the basic toxic evaluation and for the registration of these products (Barbosa *et al*., 2015).

Considering the above, it is important to carry out studies on exposure and accumulation of pesticides in stingless bees, since, by using only the honeybee, there is a risk of underestimating the accumulation of other pesticides (Boyle *et al*., 2019), since some species of stingless bees nest on the ground, use mud or resins from certain plants for their nests, so they could be more exposed to some pesticides than the bee *Apis mellifera* L. (Linnaeus, 1758; Thompson, 2016; Rortais *et al*., 2017). There have been cases where bees that live in the soil are affected by neonicotinoids applied only in the shell of the seeds and other routes that do not affect the honeybee. Therefore, it is necessary to study other pollinators, since these routes are not the same for each group of bees, nor do they affect them in the same ways (Sponsler *et al*., 2019).

Employing other bees, such as those of the Tribe Meliponini, could also reveal which practices, ways of cultivating or other methods are most harmful and which of these activities need to be modified. This is being done in Europe, where the European Food Safety Authority (EFSA) is doing research to do risk management not only for consumers, but for native pollinators that includes both pesticides and other threats (Rortais *et al*., 2017). This is an example of how more progress could be made in the sustainability of our production, by using bees of different species as indicators of pesticide effects.

For *Apis mellifera*, there are already validated methods for the chemical analysis of pesticides in pollen that have been able to detect up to 26 pesticides and these same, with adaptations, could be applied to the pollen that stingless bees store (De Oliveira *et al*., 2016). It is important to consider that these same methods or a modification of them can perhaps be used to perform analysis of environmental contaminants through the bee, honey and pollen matrix (Baldi *et al*., 2014). The presence of neonicotinoids has already been detected in *Scaptotrigona* aff. *depilis* (Moure, 1942) (De Souza *et al*., 2015). Likewise, organochlorine insecticides have also been detected in honey and pollen of *Scaptotrigona mexicana* in the Soconusco region, Chiapas, Mexico (Ruiz-Toledo *et al*., 2018).

When analyzing the above results, it is likely that DDT is still being used in Mexico despite the ban. Organochlorines can enter the food chain mainly through fatty products, but also through nonfatty products such as honey, causing damage to health. The studies carried out by Ruiz-Toledo *et al*. (2018) show the use of bees as bioindicators of organochlorine pesticides, which poses a risk to bees and human health when consuming bee products such as honey contaminated with these compounds, in addition to the presence of a wide spectrum of organochlorines despite their ban since 2000, which indicates that it is necessary to carry out more studies on their origin due to the impact they have on health of consumers. To this end, stingless bees could be a valuable tool that would allow monitoring the use of these substances.

Conclusions

The demand for food in the world is increasing every day and a strategy to ensure it in Latin America is the conservation of stingless bees, because of the service of pollination for the production of seeds and fruits, since without the help of these insects, agricultural production would not be feasible, being necessary their protection to continue receiving that ecosystem service that benefits the environment, agriculture and humanity.

According to the literature review, records of meliponines and crops were obtained in only ten countries, finding 17 genera, so it is necessary to carry out more research to evaluate other pollinators in agroecosystems and greenhouses. Stingless bees are bioindicators of the health of an ecosystem because they provide information about the impacts of environmental pollution, which can have a direct effect on human health. On the other hand, the conservation of bee populations can provide information to develop comprehensive strategies and thus contribute to food security. In addition, more studies on bees as bioindicators are needed, since most focus on the impact of these on *Apis mellifera*, when the populations most affected by the chemicals that compose them are native bees.

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