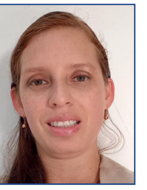
Native stingless bees, their social and ecosystem roles – a review



L. C. Caballero Méndez, D. Salazar Ríos, J. F. Chica Builes and L. N. Franco-Montoya*

Abstract

Pollinators are animal vectors such as some insects, birds, and mammals that fulfil a biological function in most terrestrial ecosystems and contribute to the genetic variability of plants. Bees are the best known pollinators. These insects constitute a highly diverse group that depend on flowers to guarantee their survival and complete their life cycle. They are considered necessary floral visitors that pollinate many plant species. Stingless bees, called meliponines, are essential pollinators in tropical and subtropical ecosystems, at elevations from sea level to 3400 metres. Their products, such as pollen and honey, have great medicinal value in human health. However, a lack of knowledge concerning their diversity, distribution, biology, and taxonomy has led to population declines, putting the pollination service they provide at risk. One of the strategies to promote their conservation is the development of meliponiculture, which is considered a productive breeding practice that, when well-managed, can ensure care and conservation of these pollinators. This review aims to analyse the importance of native bees and the products obtained from their services in the balance of ecosystems.

Key words: *biodiversity; honey; insects; meliponines; pollination; stingless bee*

Introduction

Stingless bees are a group of highly social insects considered essential pollinators of several plant species that provide pollination services for crops with economic impact (Cham et al., 2019). They constitute a vital group for tropical and subtropical ecosystems (Biluca et al., 2016). Their presence is reported in Central America, South America, Southeast Asia, Africa, and Australia (Popova et al., 2021), with more than 600 species distributed in 56 genera. They are recognised for the products provided by their hives, as well as their role in the balance of ecosystems (Biluca et al., 2017). All species in this group have an atrophied or vestig-

Lyda C. CABALLERO MÉNDEZ*, (Corresponding author, e-mail: lydaccm_27@utp.edu.co), Grupo de investigación BIOECOS, Profesora de Medicina Veterinaria y Zootecnia Facultad de Ciencias de la Salud, Universidad Tecnológica de Pereira, Pereira, Colombia; Daniel SALAZAR RIOS, Biológo, meliponicultor Fundación Najil Cab, Chinchiná, Caldas, Colombia; Juan F. CHICA BUILES, Grupo de investigación BIOECOS, Director Codegar, Pereira, Colombia, Luz Natalia FRANCO-MONTOYA, Grupo de investigación CIBAV, Profesora Asociada adscrita a la Escuela de Medicina Veterinaria, Facultad de Ciencias Agrarias, Universidad de Antioquia UdeA, Medellín, Colombia

ial stinger, and are therefore also called stingless bees (De Paula et al., 2021). However, they have achieved surprising ecological and behavioural adaptations to survive possible threats in tropical environments (Leonhardt, 2017).

One of the main activities carried out by these bees is the collection of pollen and nectar, which constitute their primary source of carbohydrates, proteins, and vitamins. These collected resources are stored in their hives to feed young and adult bees, the bee larvae, and the microorganisms that grow in the pollen (Faria et al., 2012; Steffan et al., 2019). Products such as honey and pollen are related to medicinal properties that greatly benefit human health; however, their production is considerably lower than that produced by *Apis mellifera (*Chuttong et al., 2016). These bees visit multiple types of flowers due to their feeding and foraging habits (Almeida-Braga et al., 2012), though some species can be selective, concentrating their trips on more profitable sources that provide more energy than they expend (Faria et al., 2012). Much of the diversity and distribution of these species in our territory is currently unknown, implying a lack of knowledge of the great ecosystem value they provide. The interest in developing breeding techniques for these meliponines has led to the development of meliponiculture, a productive alternative and a strategy aimed at their care and conservation. However, it can lead to the loss of hives, transmission of diseases, or genetic alterations in wild populations. Therefore, this review aims to highlight the importance of native stingless bees in the balance of terrestrial ecosystems, as well as the benefit obtained from their products and the breeding techniques used for their conservation.

Organisation

Bees belonging to the Meliponini Tribe constitute a group of insects that have populated tropical areas for about 65 million years, making them older than the common honeybee (Gennari, 2019). These bees belong to the order Hymenoptera, suborder Apocrita, family Apidae; they are also called Meliponines, Stingless Native Bees (ANSA), or stingless bees, the latter being the most frequent name and is because the size of this structure is considerably reduced and non-functional (Michener, 2013). However, the term stingless bees is imprecise, since all male bees lack a stinger; this structure is derived from the ovipositor, which makes the stinger exclusive to females (Nates-Parra and Rosso-Londoño, 2013). However, there are several groups of bees whose females have reduced and non-functional stingers; this is the case of the females of the genus *Andrena* that have stingers too small to be used for stinging, and the genus *Dioxys* and its relatives that have the smallest stingers of all bees (Michener, 2013). Meliponini colonies are organised in groups of individuals known as castes; among these groups are worker bees (infertile female workers), generally only one reproductive female per colony known as the queen, and males with remarkable similarity in size and appearance to worker bees (Aldasoro and Zepeda, 2018). The meliponines belong to a monophyletic group of four tribes (Apini, Meliponini, Bombini, and Euglossini) known as the corbiculate bees because their females have a corbicula on each hind tibia. The corbicula is a widening of the tibia, often concave, bordered by long fringes, used to transport pollen or other substances to the nest (Horacio, 2016). Meliponines are characterised by having permanent colonies, morphologically different worker and queen castes, and a vestigial or atrophied stinger; they have naked eyes and wings with reduced venation (Nates-Parra, 2001).

These bees make their nests in available cavities, such as holes in trees, walls, floors, debris, cavities resulting from the decomposition of large roots or from rodent activities, dead trees, exposed nests of termites and ants (Roubik, 2020). Some Meliponini make their own "cavities" by building a series of exposed walls around a space in which they nest; this is the case of some species of Partamona, which make their nests against walls, cliffs, or tree trunks (Camargo and Pedro, 2003). These bees build their nests using wax, but the primary material is cerumen, a material obtained from the mixture of wax with resins or gums (propolis) collected from trees and bushes; some species complement the cerumen with mud, vertebrate faeces, pieces of carrion, and more. The different types of mixtures give the cerumen variable hardness, flexibility, and heat resistance (Michener, 2013). Cerumen is a product that originates from the resin that bees collect and combine with their salivary secretions and the wax from their abdominal segments, and it is used to build and seal their hives (Ávila et al., 2018).

The heart of the nest is the brood chamber located in the centre of the nesting cavity. It contains the brood cells, and in each a bee develops from an egg until the adult emerges (Michener, 2013). The particular arrangement of the structural elements of the nest varies between the species but always contains brood cells in clusters, as in some species of *Plebeia* and *Frieseomelitta* (Figure 1A), or stratified in horizontal combs (Figure 1B), or disk-shaped, stacked and separated by columns of wax that allow the free circulation of bees, this is the most frequent case as it occurs in most genera (Gennari, 2019). The brood cells are different between these bees; the queen is the main egg layer, and is larger than the workers. In the genus Melipona, queens and workers are raised with the same amount of food. Therefore, the queens are similar in size, although with a longer and heavier body than the workers (Ribeiro et al., 2003).

The brood area is surrounded by a layered envelope called an involucre that serves for thermoregulation (Figure 2). They have a storage area outside the brood region containing ovoid containers known as pots or amphorae, where the bees store nectar, honey, and pollen. They are much larger than the brood cells and

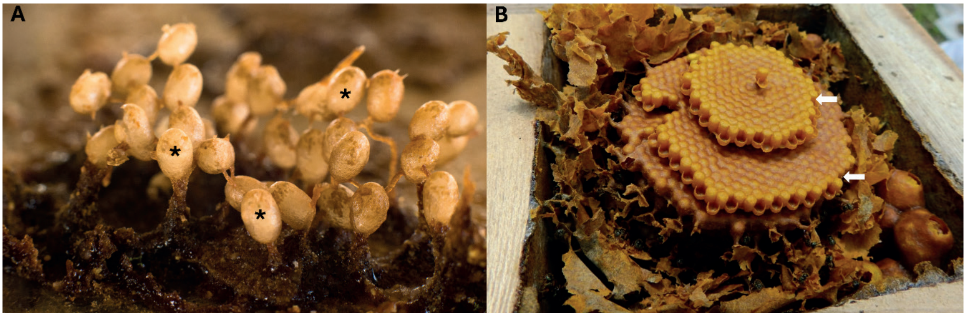


Figure 1. A) *Honey amphorae of the Franki bee *Plebeia franki*. Photographs: Daniel Salazar Rios, Najil Cab Bee Sanctuary Vereda Alto de la Mina – Chinchina, Caldas – Colombia. B) Interior of the short Angel bee *Plebeia sp.* hive. Arrows show the horizontal brood combs under construction. Photo: Ana María Vélez, Meliponario Germinato, Finca la Ermita, Vereda la Paloma, Palestina, Caldas.

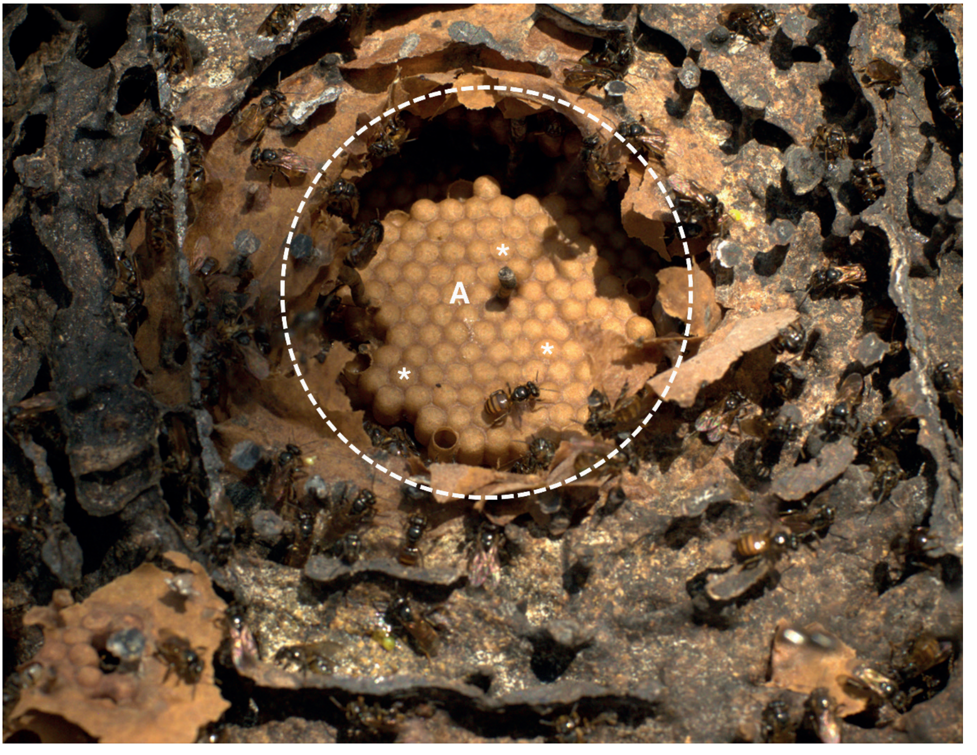


Figure 2. Nest of a Meliponini (*Partamona peckoltia*). A) In the centre are the brood discs, formed by the union of the brood cells*. These structures are surrounded and protected by the involucrum, dotted line. Photography: Daniel Salazar Rios, Najil Cab Bee Sanctuary Vereda Alto de la Mina – Chinchina, Caldas - Colombia.

are generally made of thicker dark wax, although some species make food pots with pure wax (Michener, 2013).

The entrance tube to the nest has a shape that is generally species-specific, and in some cases, enables identification of the genus. It is a straight tube of clear wax or dark cerumen in the genera *Scaptotrigona*, *Nannotrigona* or *Tetragonisca* (Figures 3A-B), or shaped like a funnel or flattened trumpet of cerumen mixed with mud in *Partamona* and some species of *Melipona*, or a hole through which only one bee can pass as in *Plebeia franki* (Figure 3C) (Michener, 2013).

Meliponini distribution in Colombia

Stingless bees are credited with 40% to 90% of the pollination of wild plant species in several tropical and subtropical ecosystems. They are often flower visitors, and their disappearance is thought to significantly modify rainforest communities (Cham et al., 2019). They are considered floral generalists, collecting pollen and nectar from a wide variety of species and playing an important role in the conservation of animal and plant communities (Almedida-Braga et al., 2012). Although they are considered important pollinators of many plant species, in Colombia, very

Figure 3. A-B) Entrance to the nest of the Angel Bee (*Tetragonisca angustula*). C) Entrance to the nest of the Mosquito Bee (*Plebeia franki*). Worker removing a corpse from the hive. Photographs: Juan Fernando Chica Builes and Daniel Salazar Rios, Najil Cab Bee Sanctuary Vereda Alto de la Mina – Chinchina, Caldas – Colombia.

few proposals lead to research on stingless bees and their relationship with wild or cultivated plants (Nates-Parra, 2001, 2016).

In Colombia, approximately 120 stingless bee species have been reported, grouped into 14 genera and nine subgenera. Currently known as "*angelitas,*" "*alá,*" "*perreras,*" "*candela,*" and "*guare.*" However, their name may vary depending on the region of the country. Meliponini species are preferably distributed in dry and humid tropical forests at elevations from sea level to 3400 m (Nates-Parra, 2016). In Colombia, around 34 species of native stingless bees are raised, which represents between 28% and 32% of the species reported for the country; however, in regions such as Orinoquia, Amazonia, and Pacific the distribution of these species is not known (Nates-Parra and Rosso-Londoño, 2013). Genera such as *Frieseomelitta, Tetragona, Tetragonisca, Plebeia,* and *Scaura* are not fully characterised, with little knowledge of their taxonomy and diversity (Pedro et al., 2013). There are genera and species that are more frequently present, and the most studied species generally have a wider distribution range and easy adaptation to different environments such as cities. Among the managed species in meliponiculture, the most common is the Angelita (*Tetragonisca angustula*), and other genera such as *Nannotrigona, Scaptotrigona, Melipona,* and *Paratrigona* (Nates-Parra and Rosso-Londoño, 2013).

Characteristics of stingless bee honey

Bees of the Meliponini tribe produce and store less honey compared to *Apis mellifera* bees (Chuttong et al., 2016). A hive of meliponines produces approximately between 1 and 5 kg honey per year, sometimes less, while *Apis mellifera* can produce 20 kg honey per year per hive. In turn, although meliponine honey is available in the market, its price is considerably higher (US 100/Kg) compared to *Apis mellifera* (USD 20-40/Kg) (Ávila et al., 2018). However, honey from *Meliponinae* is not included in international standards for honey, so there is no regulation by food control authorities, and there are no quality control declarations for human consumption (Chuttong et al., 2016). Currently, in South America, countries such as Argentina and Brazil have national regulations in effect for the institutional regulation of honey produced by bees from the *Meliponinae* Tribe (Vit et al., 2016). In Colombia, the honey standard was revised in 2006, where an annex was included for honey produced by native bees (Icontec, 2012).

Honey from stingless bees has been a traditional natural remedy for many years (Sánchez-Chino et al., 2019). It is considered a product with great value for human health since it is used as a therapeutic alternative for the treatment of respiratory, dermatological, and gastrointestinal diseases, giving it added value even over *Apis mellifera* honey (Ávila et al., 2018). Other properties have been reported, including its anti-diabetic and anti-cancer effects, and benefits for wound repair, and the treatment of eye infections and for fertility (Zulkhairi, 2018).

However, its growing interest lies in its components such as enzymes, organic acids, amino acids, proteins, carotenoid-type substances, minerals, and polyphenols, among others in ecosystems (Biluca et al., 2017). It is attributed as having antiseptic, antimicrobial, anticancer, anti-inflammatory, estrogenic, immunostimulant, antiallergic, and wound-healing properties, and it also has the ability to promote the cellular functions of red blood cells (Da Silva et al., 2013). Additionally, its use in eye diseases such as cataracts, glaucoma, and pterygia has been reported (Gamboa et al., 2009).

Meliponini honey is a concentrated mixture of reducing sugars, mostly fructose, glucose, and sucrose. However, the content of reducing sugars is lower compared to *Apis mellifera* honey. Meliponini honey sugar content may also vary depending on the region, and the dominant flora and vegetation in the area (Ávila et al., 2018). In addition, other disaccharide and oligosaccharide sugars, such as sucrose, maltose, maltotriose, and panose, among others, have been reported (Rao et al., 2016). pH values from 3.1 to 3.6 have reported. This acidity is related to the balance of organic acids in the honey, which varies according to the floral composition, bee species, fermentation of sugars to alcohol by microorganisms, and oxidation to carboxylic acids (Ávila et al., 2018). The mineral content depends on the absorption of nutrients through the soil by the plant and the environment where the bees collect the nectar to produce honey. Among them, potassium is mainly found, followed by calcium, sodium, magnesium, and manganese (Biluca et al., 2016). However, elements such as iron, copper, sulfur, and chlorine have been reported (Cardona et al., 2019).

Among the honey compounds that have received special attention in research are those with antioxidant capacity, such as phenolic acids, flavonoids, and the enzymes glucose oxidase and catalase, since they contribute to preventing diseases related to oxidative stress (Gamboa et al., 2009). In turn, phenolic acids and flavonoids are considered markers of the botanical origin of honey and contribute to its colour, smell, and flavour (Vit et al., 2016). These phenolic compounds are related to botanical resources such as pollen, nectar, and resins, and therefore, honey from different floral origins have different bioactive properties (Gamboa et al., 2009). The content of antioxidant compounds in honey contributes to its antioxidant capacity and depends on the floral source visited by the bee and the entomological origin (Sousa et al., 2016). Its antimicrobial properties are attributed to its high sugar concentration and the presence of peroxide-type compounds, mainly hydrogen peroxide and polyphenols (Ávila et al., 2018). Antimicrobial activity has been described against *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, and fungi such as *Candida albicans*, *Saccharomyces* *cerevisiae,* and *Aspergillus niger* (Rao et al., 2016).

Characteristics of stingless bee pollen

Pollen characteristics vary according to climatic conditions and botanical and geographical origin (Biluca et al., 2017). Composed of carbohydrates, proteins, lipids, vitamins, polyphenols, sterols, crude fibre, amino acids, fatty acids such as palmitic, oleic, and linoleic acids, and minerals such as sodium, potassium, calcium, and magnesium, among others, pollen has been attributed to antimicrobial, antioxidant, anti-inflammatory, anti-mutagenic, and chemoprotective activities, among others (Belina-Aldemita et al., 2019). This has led to its use as a food supplement, as it is considered the only perfectly complete food (Da Silva et al., 2014). Pollen provides bees with minerals, sugar, proteins, lipids, vitamins, starch, and nitrogen essential for the growth of young individuals and to supply the nutritional requirements of the larvae and adults of these bees (Serra et al., 2012; De Paula et al., 2021).

Beginnings of Meliponiculture

Various cultures have long used stingless bees, and their products, used as food, medicine, utensil making, crafts, and ceremonial ornamentation, have been reported (Paris et al., 2018). Cultures such as the Malay, Arab, Hebrew, Persian, Roman, Indian, and Chinese have traditionally consumed the honey of these bees (Fatima et al., 2016). Historically, the first type of approach that was presented was the collection and use of wild colonies by honey and wax hunters, who managed to harvest the honey deposits of bees, even from highly defensive species, by tolerating their bites, using tools to access bee nests located in tree trunks or on the ground, or even using techniques to reduce their aggressiveness (Jones, 2013). This was the case of the Paí Kaivás of Paraguay who had songs dedicated to bees, as well as the Uwa people who inhabited the Sierra Nevada del Cocuy located in the eastern Colombian mountain range, who considered bees as daughters of the sun, responsible for promoting fertility, and assisting the beginnings and continuity of life, both in ancestral times and in social life (Falchetti, 2002). The Kayapó Indians of Brazil structured their social organisation model based on social insects, including stingless bees, ants, and wasps; in turn, they used crushed toxic leaves of *Tanaecium nocturnum* [*Bignoniaceae*] to manage bees by sedating them for 1 or 2 minutes to extract their honey (Jones, 2013). The indigenous tribes of South America were considered exclusive collectors of products such as honey, pollen, and Beeswax from bee hives in tropical forests (Gonzalez, 2012). Later, the use and maintenance of hives around a shelter or home began; the bees took advantage of the section of a trunk or branch of a hollow tree; the trunk was cut in such a way that it could be opened and resealed, allowing sustainable extraction without destroying the nest (Cortopassi, 2006). The development of advanced techniques for the management of colonies and the manufacture of artificial nests was aimed at the breeding of meliponines, specifically the Xunan-Kab species [*Melipona beecheii*] and commercialisation of its products. This origin of these practices were reported in advanced sedentary cultures of the Mesoamerican tropics, more than 1400 years ago among the Mayans of the Yucatan Peninsula, and then spread to other indigenous Central American cultures (Obiols and Vásquez, 2013). The Mayan codices and some chronicles of the Spanish described large concentrations of bee colonies of the genus *Melipona* they found upon their arrival in the Yucatan Peninsula (Gómez, 2017). The importance of these practices is revealed above all by the existence of the god of bees [Ah Mucen Kab] and the rituals of handling and using hive products, considering the honey produced by Xunan-Kab as a sacred product and used as payment of taxes to the Aztecs (Cortopassi, 2006). (Figure 4).

Current meliponiculture

The term meliponiculture was initially coined by Pablo Nogueira Neto in Brazil (Nogueira, 1997), to name the set of techniques and processes used in the sustainable breeding and management of stingless bees (Pedro et al., 2013). Unlike traditional meliponiculture, originating in temperate regions of Europe and Asia that use a single genus [*Apis*] and two species of bee: the western honeybee (*Apis mellifera*) and the eastern honeybee (*Apis cerana*), meliponiculture relies on the use of many species (Michener, 2013). This large number of species also implies a high level of complexity and behavioural diversity that does not allow for the development of uniform technological packages for breeding and use. It is impossible to work with these species uniformly, as with *Apis*. For this reason, many boxes of different styles and sizes have been built and tested (Pedro et al., 2013) (Figure 5).

Figure 4. Fragment of the Tro Cortesiano codex where Mayan deities such as Chaac perform beekeeping practices. Above is the representation of the Xunan Kab bees [*Melipona beecheii*]; below is the extraction and use of honey from their hives (Gonzalez Acereto, 2012).

Figure 5. Some types of bee hives of the Meliponini tribe: A. High-tech hive type AF (Ailtón Fontana), B. Basket hive, C. High-tech hive type JCW (José Carlos Werzinoski), D. INPA type hive. Photographs: Daniel Salazar Rios, Najil Cab Bee Sanctuary Vereda Alto de la Mina – Chinchina, Caldas – Colombia.

Meliponiculture is an activity that can complement and strengthen agriculture and the conservation of natural ecosystems. However, it has been characterised as a relatively recent and low-tech activity, with knowledge transmitted mainly orally over time (Eardley, 2013). Research into the biology of native bee species in each ecosystem and their essential role in pollination significantly contributes to meliponiculture, allowing the design of cultural practices that benefit their breeding and development (Cortopassi, 2006). Around 28% of stingless bee species in Colombia are used in meliponiculture. However, complete identification at the species level of all stingless bees has not been possible, which prevents understanding the distribution of these bees in various areas of our country (Biesmeijer, 2006).

Risks and threats

Assessments of risks for pollinators other than *Apis mellifera* are still scarce (Cham et al., 2019). Several European countries have detected a considerable decrease in the number of wild bee species (Biesmeijer, 2006). Therefore, there is evidence of the disappearance of bees, but in general, the precise extent and magnitude of this disappearance or decrease is unknown (Nates-Parra, 2016). In the Neotropics, one of the main threats with the most significant impact on the bee population is human activities, such as habitat loss and fragmentation, honey hunting, land use change, intensive use of herbicides and pesticides, environmental pollution, the introduction of invasive species, the proliferation of pathogens and climate change (Nates-Parra, 2016; Freitas, 2009). Additionally, environmental factors such as droughts, hurricanes, and fires, among others, can endanger their survival (Nicholson, 2020). There are also risks associated with the management of colonies, since the extraction and displacement of hives outside their place of origin can affect the ecological and genetic structure of endemic bee populations and generate possible inbreeding in populations transported outside their area of occurrence in the long term (Vollet, 2018). In turn, the destruction of colonies to obtain honey and pollen constitutes an additional threat (Nates-Parra, 2016). The main problem for their conservation is misinformation since much of their wealth, diversity, taxonomy, distribution, population dynamics, and the impact of human activities are unknown (Cham et al., 2019).

Environmental education and native bees

The BIOECOS (Biodiversity and Ecosystem Conservation) research group belonging to the Veterinary Medicine and Animal Husbandry program attached to the Faculty of Health Sciences of the Technological University of Pereira. It has been working on environmental education with populations of children, youth, and adults from rural, peri-urban and urban schools, emphasising the care and conservation of native stingless bees present in the coffee belt. This strategy aims to raise awareness among the general population about the importance of caring for and conserving our native bees, through recreational activities such as games, planting gardens, identifying hives in educational environments, providing fruit-based snacks to raise awareness among the school population about pollination and its benefits, talks led by beekeeping experts on the importance of our bees in the pollination and sexual reproduction of flowering plants, and identifying hives. (Figure 6). These sessions allow for the creation of an environmen-

Figure 6. Environmental education for preserving native bees in rural elementary schools in the coffee region of Colombia

tal culture about the care of our biological resources and their social and ecosystem importance for many animal and plant species, and even for our survival.

Perspectives

Stingless bees are an essential asset in the pollination processes of our ecosystems. However, the need for more information about their diversity, distribution, and taxonomy limits us from clearly understanding their conservation status. The Technological University of Pereira promotes environmental education aimed at caring for and conservating these native species. However, it is pertinent that the population involved in the management of biodiversity participates in the design and execution of proposals aimed at the conservation of the pollinating fauna of our country.

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Domaće pčele bez žalca, njihova uloga u društvu i ekosustavu – pregledni članak

Lyda C. CABALLERO MÉNDEZ, Grupo de investigación BIOECOS, Profesora de Medicina Veterinaria y Zootecnia Facultad de Ciencias de la Salud, Universidad Tecnológica de Pereira, Pereira, Colombia; Daniel SALAZAR RIOS, Biológo, meliponicultor Fundación Najil Cab, Chinchiná, Caldas, Colombia; Juan F. CHICA BUILES, Grupo de investigación BIOECOS, Director Codegar, Pereira, Colombia, Luz Natalia FRANCO-MONTOYA, Grupo de investigación CIBAV, Profesora Asociada adscrita a la Escuela de Medicina Veterinaria, Facultad de Ciencias Agrarias, Universidad de Antioquia UdeA, Medellín, Colombia

Oprašivači su životinjski prijenosnici poput nekih kukaca, ptica i sisavaca koji doprinose genetskoj raznolikosti biljaka i, samim time, ispunjavaju biološku funkciju u većini kopnenih ekosustava, pri čemu su pčele kukci koji su najpoznatiji širokoj populaciji. Ovi kukci predstavljaju vrlo raznoliku skupinu koja ovisi o cvijeću da bi preživjela i dovršila svoj životni ciklus. Oprašivači se smatraju potrebnim posjetiteljima cvijeća koji oprašuju brojne biljne vrste. Među najpoznatijim kukcima su pčele bez žalca, zvane meliponini, bitni oprašivači tropskih i suptropskih ekosustava. Ove pčele su rasprostranjene između 0 do 3400 mnv. Uz to, njihovi proizvodi, poput peludi i meda, imaju veliku medicinsku vrijednost za ljudsko zdravlje. Međutim, nepoznavanje njihove raznolikosti, rasprostranjenosti, biologije i taksonomije dovelo je do opadanja njihovih populacija, što predstavlja rizik za uslugu oprašivanja koje one pružaju. Jedna od strategija za promoviranje njihovog očuvanja jest razvoj meliponikulture, koja se smatra produktivnom praksom uzgoja, a koja, kada je dobro upravljana, može omogućiti njihovu skrb i očuvanje. Ovaj pregledni članak ima za cilj analizirati važnost naših domaćih pčela i proizvoda dobivenih od njih u ravnoteži ekosustava.

Ključne riječi: *bioraznolikost, med, kukci, meliponini, oprašivanje, pčele bez žalca*