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Non-*Apis* bee pollinators: A way out to the future pollinators' challenge

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Abstract
Insects contribute majority of pollination activities in the world and among them bees representing as the most economically valuable pollinators. Due of its eusocial behaviour, honey bees are believed to be the most promising insect group for pollinating crop plants. However, a variety of anthropogenic activities that have resulted in habitat loss or alteration, misuse of pesticides, development of parasites and diseases, and introduction of alien species have caused a rapid fall in honey bee numbers, raising concerns about the pollination services provided throughout the world. In addition, a lot of plants have developed sophisticated pollinator-favouring mechanisms, such as poricidal anthers, restricted nectar production and primary specialised pollen release systems, which make honey bees unfavourable in these plants' pollination processes. Therefore, diversifying crop pollinators might assist in achieving pollination services when the usual pollinator (honeybees for the majority of crops today) is not present in adequate numbers. In this situation, native non-*Apis* bees will provide a solution to the impending pollinators' dilemma in the scenario of global pollination. Non-*Apis* bees have several advantages over honey bees, and they can flourish with basic management techniques unlike honey bees. But little is known about these wild bee pollinators, limiting their use in pollination activities. Thus, the present article lightens up about this major group of non-*Apis* bee pollinators focusing their diversity, nesting biology, pollination role as well as management practices.

Keywords: Pollination, honey bees, Non-*Apis* bees, anthropogenic activities, nesting biology, poricidal anthers

Introduction

The need for food security is growing as a result of issues including climate change, changing land uses, habitat destruction, and an expanding human population. The number and quality of nuts, fruits, oils, and other crops produced can be enhanced by proper pollination (Giannini *et al.* 2015) [24]. More than 75% of the world's 115 major crop species rely on animal pollination, while only roughly 28% rely on wind and self-pollination (Klein *et al.*, 2007) [33]. Market pricing indicate that animal pollination increases annual crop production by USD 235-577 billion, with the Mediterranean region, Southern Europe and Eastern Asia and benefiting the most economically (Potts *et al.* 1016) [52]. Pollination also benefits ecosystems in various ways, such as increasing biodiversity and boosting food production without endangering the environment (Montoya *et al.* 2020) [45].

The vast majority of animals that visit plants and spread pollen are insects, such as flies (Diptera), beetles (Coleoptera), butterflies (Lepidoptera), and, most importantly, bees (Hymenoptera: Apoidea). Bees are thought to be the most efficient pollinators due to their morphological modifications for pollen gathering (Abrol 2012) [2]. Bee species specialised in pollen and nectar gathering and have a direct relationship to floral morphology. Bees mistakenly lose pollens on the stigma that fertilises ovules while collecting nectar, pollen, and oils. They are classified into two major groups: *Apis* bees (Also known as honeybees) and non-*Apis* bees (Bumblebees, stingless bees, and other solitary bees). Due to their highly social behaviour (Eusociality) and colony manageable traits, honey bees (*Apis mellifera*) have assumed a dominating position in commercial pollination throughout the world. So far, honey bees have been widely credited with pollination services, but new research has demonstrated that non-*Apis* bees also play critical roles in supporting different plant species and are becoming increasingly vital in agriculture (Vaughan *et al.* 2014) [73]. Because of our limited understanding of how wild bees build their nests and our reliance on the controllable honey bees, which also produce by-products, we have historically undervalued the contribution of wild bees. This review is focused to enlightening the importance of non-Apis bee in response to their diversity, nesting biology and management for better understanding and utilization of them in pollination services.

Importance of non-*Apis* bees

Honeybees may not always be the best pollinators because of a variety of issues, including differences in body size and flower size, a lack of enough nectar, and specific pollen release mechanisms in some plants, such as those with poricidal anthers (Kearns and Inouye, 1997) [32]. Therefore, increasing the variety of crop pollinators would be helpful in guaranteeing pollination services when the main pollinator (especially honeybees for the majority of crops today) is not present in sufficient numbers. There are many difficulties in modern beekeeping, including problems with parasitic mites, illnesses that affect honey bees, the inability of honey bees to function in cold temperatures, and unfavourable weather. The honey bees' general utility as a pollinator for agriculture is threatened by these issues (Torchio, 1990). This adds to the recent, widespread losses in honey bee numbers (Colony Collapse Disorder), which are of worry to beekeepers, growers of insect-pollinated crops, and policymakers. (Abrol, 2012) [2].

Numerous crops are successfully pollinated by wild and domesticated non-Apis bees in addition to honey bees. The use of bumble bees, primarily for the pollination of greenhouse tomatoes, the solitary bees Nomia and Osmia for the pollination of orchard crops, Megachile for the pollination of alfalfa, and social stingless bees for the pollination of coffee and other crops are examples of managing non-Apis species for agricultural pollination (Slaa *et al.* 2006) [66]. Fruit set was doubled by non-Apis bee visits compared to visits from honey bees. Both non-Apis and Apis bee group interactions with flowers independently induced fruit set. Therefore, the pollination services offered by non-Apis bees were supplemented rather than supplanted by the presence of controlled honey bees in pollination activities (Garibaldi *et al.* 2013) [22].

Diversity of bees in India

Bees are the aculeate hymenopterans representing 7 families, namely Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Melittidae and Stenotritidae under superfamily Apoidea, represent a great diversity worldwide (Michener, 2007) [44]. In India six families were found, as family Stenotritidae exclusively found in Australia and, so far no species has been recorded from anywhere else in the world. All the families contained non-Apis bees and had well distribution. India is home to 766 species that are organized into 71 genera, 26 tribes, and 14 subfamilies under the umbrella of six families of the superfamily Apoidea (Saini and Chandra, 2019) [63].

Andrenidae: The presence of two sub antennal sutures beneath each antenna is the Andrenidae's most distinguishing feature. It is only represented in India by the sole genus Andrena Fabricius 1775, which has 23 species.

Apidae: Long-tongued bees are members of this important global family. A total of 235 species, belonging to 24 genera in 13 tribes and three subfamilies-Xylocopinae, Nomadinae, and Apinae-have been identified in India.

Colletidae: The female members of the family Colletidae have short, frequently broader than long, truncate, bilobed, or bifid glossae. Two genera and two subfamilies, Colletinae and Hylaeinae, with close to 35 species each, are known from India.

Halictidae: This significant global family is also referred to as sweat bees. The most distinguishing feature of the Halictidae is the lacinia, which extends up to the anterior side of the labiomaxillary tube and ends in a setose, frequently finger-shaped projection far above the rest of the maxilla. A total of 226 species, which are members of 15 genera and three subfamilies, namely Halictinae, Nomiinae, and Rhophitinae, have been identified thus far.

Megachilidae: Also known as leaf-cutter and mason bees, this large family is found all over the world. Long-tongued bees of the Megachilidae family have a rectangular labrum that is longer than it is wide and is extensively articulated to the clypeus. With 243 species across 27 genera in 5 tribes and 3 subfamilies-Lithurginae, Megachilinae, and Pararhophitinae-it is the largest family in India.

Melittidae: This family is distinguished by a big, dull propodeal triangle and a broad disc and small apicolateral process on the male S7. With only four species and two genera, it is the smallest family of bees in India.

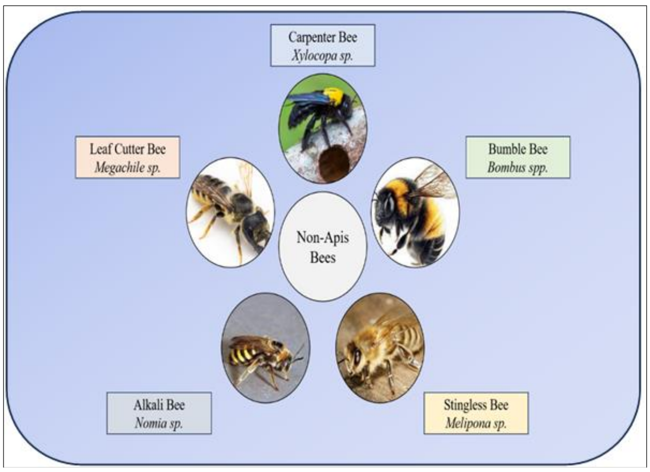

Fig 1: Major groups of non-*Apis* bees

Carpenter bee

The tribe Xylocopini (Apidae: Xylocopinae) of large carpenter bees is a group of bees that lives in tropical and subtropical regions and is found in the genus *Xylocopa* (Leys *et al.* 2000) [38]. Carpenter bees have many benefits over other non-Apis bees in agricultural pollination because they eat a variety of plant types throughout their lengthy activity seasons. They can buzz-pollinate flowers, which gives them even greater versatility as crop pollinators (Somanathan *et al.* 2019) [68]. Sometimes they will even continue to work into the moonlight hours.

Diversity

Carpenter bees are widespread over the world, with numerous species occupying varied types of habitats. North America, Europe, Asia, and some regions of Africa are where you can find them most frequently. There are over 500 species in 31 subgenera of the genus *Xylocopa*. There are 16 species that are spread throughout the desert regions of areas of Europe, from western China to the east. In the Indian area, the genus *Xylocopa* Latreille 1802 of Carpenter bees contains 45 species and subspecies, according to Gupta (2003) [27]. *Xylocopa auripennis, Xylocopa hemichlora, Xylocopa phenachroa,* and *Xylocopa semipurpurea* are the most prevalent species in India. (Abrol *et al.*, 2013) [1].

Nesting biology

Carpenter bees are well-known for being able to construct their nests in tunnels in dense wood, logs, stumps, or dead tree branches (Richards, 2020) [59]. Carpenter bees, as their name suggests, build their nests underground in dead or decaying wood, with the exception of the subgenus *ProXylocopa*, which builds its nests in the ground (Gottlieb *et al.* 2005) [25]. The females spend about a week building their nests by using their powerful and well-developed mandibles to dig tunnels or holes in the chosen wood (Carpenter nesting). There are two primary types of nests that wood-nesting carpenter bees build: (a) unbranched (also known as linear), which have tunnels running in either one or both directions from the nest entrance. Reeds or other hollow or soft-centered plant materials are typically used to build linear nests. (b) Branching nests (tunnels with more than two) are typically built out of wood or tree trunks (Gerling 1989) [23]. Some species only have one brood per year, whereas others have multiple broods (Steen and Schwarz, 2000) [70]. Carpenter bees have an 8 to 12 months active season, depending on the species (Gerling *et al.* 1989) [23]. In temperate climates, carpenter bees hibernate during the cold months (Steen and Schwarz, 2000) [70] but come out to graze on warm winter days.

Management

The requirement to mass-raise native pollinators rather than gather them from nature is a significant barrier to their commercial usage in agriculture. A crucial step in this strategy is to develop effective mass-rearing procedures for *Xylocopa* The creation of nest boxes that are put in natural settings to improve nesting success has been the main focus of efforts to mass-rear carpenter bees. Skaife (1952) [65] built observation nests out of bamboo tubes and moved *X. caffra* that was hibernating into them. After emerging from hibernation, the majority of the females stayed in their nests. The overall layout of Langstroth honey bee hives served as the basis for Oliviera and Freitas' (2003) [49] design and testing of nest boxes for *X. frontalis*. Nine wooden frames were modified to act as individual *Xylocopa* nests in these boxes. These boxes were colonized at rates ranging from 19% to 52%, and the percentage of males in the developing brood was 0.38. It is anticipated that knowledge of the potential reproductive problems and their physiological mechanisms will make it easier to establish successful captive breeding techniques for *Xylocopa*.

Bumble bee

The pollination of cultivated and wild plants by bumble bees (Hymenoptera, Apidae; Bombini) contributes to global food security. Because they have longer tongues than honeybees, they are far more effective at pollinating deep-throated flowers. According to Corbet *et al.* (1993) [10], bumblebees often feed in cold, temperate environment at higher elevations that is unsuitable for honeybees and solitary bees. In light of this, they play a crucial pollination role, particularly in alpine habitats (Yu *et al.* 2012) [79]. In greenhouses, bumble bees (*Bombus* spp.) can be employed for pollination because of their behavior, particularly "buzz pollination" (Sowmya 2015) [69].

Diversity and distribution

Bumble bees are found in more than 300 different species throughout the northern temperate regions of Asia, Europe, and North America. Numerous nations across the world, including Japan, Korea, France, Italy, United Kingdom, New Zealand, Germany, Canada, Sweden, New Zealand, China, and Finland, United States, have conducted substantial research on the bumble bee fauna**.** From the United Kingdom, more than 25 species have been identified (Prys-Jones and Corbet 1987) [53]. 48 species of the genus *Bombus* have been identified in India, 30 of which are native to the Kashmir Himalaya (Williams *et al.*, 2008) [78]. *Bombus waltoni* Cockerell, *Bombus keriensis* Morawitz, *Bombus asiaticus* Morawitz, *Bombus personatus* Smith, *Bombus rufofasciatiucus* Smith, *Bombus haemorrhoidalis* Smith, and *Bombus tunicatus* Smith are some of the native bumble bee species found in Himachal Pradesh.

Nesting biology

Eight different types of landscapes were found to have bumble bee nests: agricultural, forest, alpine, dune, grassland, forest edge, grassland, urban, and tropical forest. (Liczner and Colla, 2019) [39]. According to the research, bumble bees choose darker and corner sides of the ground and build involucrum to shield their nest from the outside environment (Abrol, 2012) [1]. The composition of bumblebee nests' materials differed based on the nests' location on the ground. In many cases, relinquish mammal burrows or nests were used as underground nests (Hofmann *et al.* 2004) [30], as well as other ground cavities or holes. According to several research, entrances to underground burrows would occasionally be covered with vegetation (Either dry or living), and this is thought to assist keep the nest from being discovered (De Oliveira *et al.* 2015) [15]. Surface nests were surrounded by specific flora or made of plant material. Tropical forest surface nests were made of chopped leaves, dried grass, and twigs (Hines *et al.* 2007) [29]. The bumblebees built their nests in a dome-like form, serving as protective shelter for the entire colony. Furthermore, the nests were frequently connected to other types of vegetation, such as bushes or trees, in order to serve as structural supports (Hofmann *et al.* 2004) [30].

Management

Queens captured from the spring flowers were housed separately in two chambered boxes and hoarding cages kept at a temperature of 25-30 °C and 6-70% relative humidity. 50 percent sucrose solution and corbicular pollen were fed to the queens **(**Abrol, 2012) [2]. Macfarlane *et al.* (1990) [41] have also raised spring collected queens housed in two screen cages and fed with a 50% sugar solution and pulverized corbicular pollen while maintaining a temperature of 18-25 °C. The majority of the researchers reported that springtime queens captured had been successfully domesticated.

Long-tongued Bombus species are trap nested (Trap nest boxes or domiciles are placed in the environment to trap founding colonies) and sold to provide pollination services to red clover (Donovan 2001) [19]. Domiciles (Man-made nesting boxes) have been created and used to increase the number of bumble bees in agroecosystems. Occupancy was discovered to increase over successive years (Barron *et al.* 2000) [8].

Alkali bees

It is a highly social solitary bee that makes its nests in great numbers in silty or fine-textured saline soils. (Abrol *et al.* 2013) [1]. The alkali bee, *Nomia* spp. (Hymenoptera: Halictidae), is a very productive pollinator used to pollinate leguminous crops on a big scale (Cane, 2002) [9]. Alkali bees resemble honey bees in size and they have stripes across their abdomen that is iridescent copper-green.

Diversity and Distribution

There are 600 species in the subfamily Nomiinae of the Halictid family of Hymenoptera, with the exception of South America (Astafurova and Pesenko, 2005) [7]. *Nomia melanderi* is an important and well-researched species of alkali bee. In India, this subfamily is recognized by 15 genera and 72 species, 48 of which are under 13 genera and are found in south India (Pannure and Belavadi, 2017) [50]. There are at least five species of the genus *Hoplonomia* Ashmead in India, which has a range that is primarily Oriental (Ascher & Pickering, 2021) [5]. According to Udayakumar and Shivalingaswamy (2018) [72], *Hoplonomia westwoodi* (Gribodo, 1994) [26] is a widespread species in southern India and is a significant pollinator of a variety of cultivated crops.

Nesting biology

The quality of alkali bee nesting sites, whether natural or managed, is determined by three critical criteria such as soil moisture, soil composition and texture, and vegetation. A suitable bed must meet a few fundamental characteristics. It needs a moisture source that can rise to the surface. This often calls for a hardpan layer to be placed at least a foot beneath porous soil, which tends to retain moisture and allow it to travel from the supply source to the surface. Situations should allow for quick surface water drainage. There shouldn't be more than 7% clay-sized particles in the underlayer, which should have a texture ranging from silt loam to sandy loam. The surface should be smooth but without a crust. It creates individual nests in the ground, up to 100 nests per square foot of soil. Alkali bees are sociable and can build up to 100,000 nests in a 40X50 feet space. There are normally 15 to 20 cells in a single comb-shaped cluster. Each cell is an oval cavity about one-half inch long, somewhat larger than the main tunnel, lined first with earth and then with a waterproof clear liquid sprayed with the bee's glossa. Bees built nests by using their mandibles to dig the ground and their legs to push the mud outside. (Vijayakumar *et al.* 2022) [75].

Management

Alkali bees need a certain kind of soil to build their nests, which is a mixture of clay and salty sand with a moisture level of 25%. One to 20 acres of artificial nesting places can be created by creating a hole that is 1 m deep. The bottom is covered with a layer of plastic, and then a 15 cm layer of fine gravel or sand is added on top of it. Another layer of fine sand and clay measuring about 85 cm thick is placed on top of that. To draw moisture from the bottom layer, 2 to 5 kg of salt are mixed into the top layer per square meter. Water is delivered to the bottom layer up to a specified height. Plastic drain tubes have been designed as a more straightforward method of providing water to the nesting area. Just the top layer of the earth is sprayed with salt. Bees can be moved from one nest location to another by relocating blocks with pupae that have overwintered (Abrol, 2012) [2].

Leaf cutter bees

Based on their shape and the material they utilize to line their brood cells, megachilid bees can be roughly divided into three groups: Mason bees are the most common, and they primarily employ mud and masticated plant materials. Resin bees, which primarily use plant resin; and true leafcutter bees, which primarily cut and use live leaf pieces. (Michener, 1964 and 2007) [43-44]. Numerous kinds of leafcutter bees visit blossoming alfalfa. As its name suggests, this very gregarious solitary bee fills its nests with circular sections cut from alfalfa leaves, however it will also cut sections off the petals of large decorative flowers. Above earth, the nests are located in tiny holes or hollow tubes. The adult bee, which is charcoal-gray in color, is only marginally bigger than a housefly. (Abrol, 2012) [2].

Diversity and distribution

The third-largest bee family, Megachilidae, is a global one with 4,097 known species worldwide (Ascher & Pickering, 2015) [5]. It contains Megachile rotundata, the most widely utilised managed solitary bees in the entire globe (Pitts-Singer & Cane, 2011) [51]. A native of Africa named *Megachile* (Eutricharaea) *concinna* Smith is currently common in the Caribbean and North America and was just discovered in Argentina (Alvarez *et al.* 2012) [4]. 75 species from the tribe Megachilini have been identified in India (Gupta, 1993) [28], 16 of which are from the genus *Megachile* Latreille. There have been reports of *Megachile elfrona* in Gujrat, Rajasthan, and Madhya Pradesh (Kumari, 2020) [36]. From Punjab, India, Kumari and Kumar (2016) [10] reported three species of the Megachile genus, including *M. anthracina, M. carbonaria,* and *M. elizabathae* Bingham. Eight species of the Megachilidae family were discovered in Uttarakhand, India, of which six belonged to the genus *Megachile* and two to the genus *Coelioxys*. Seven species of the *Megachile* genus were recently discovered in five different Indian states, according to Sardar *et al.* (2021) [64], and *M. lanata* was discovered for the first time in Assam. Veereshkumar and Kumarnag (2018) [74] reported the family Megachilidae from Bengaluru, Karnataka, India, containing six species: *M. lanata, M. anthracina, M. lerma, M. disjuncta, L. atratus,* and *M. bicolor.*

Nesting biology

Leafcutter bees build their nests aboveground in rock crevices, pithy stems of trees and canes, and man-made constructions such as hollow metal tubes (Litman *et al.*, 2011) [40]. Depending on the area, the female bee emerges between May and July, mates, and then goes in search of a nesting hole. She prefers a tube or tunnel that she can just barely squeeze through. When she searches for one and starts building a cell there. She constructs the first cell with recently cut, rectangular pieces of leaves at the base of the tube (Abrol, 2012) [2]. A brood cell has leaf discs that are different sizes and shapes. The brood cells are divided using the leaf discs as well (Sabino and Antonini, 2017) [62]. The core layer of the roll is constructed by individuals of most leafcutter bee species using leaves from a single plant species. A much larger disc cut from the same or a different plant species may be used by the bees to seal the nest (Sabino & Antonini, 2017) [62]. Then a combination of nectar and pollen is poured into this cell until it is about halfway full. The cell is covered with circular pieces of leaves, and an egg is placed on the food. The process is continued until the tube is almost completely filled with cells, The process is continued until the tube is almost completely filled with cells, immediately above the initial cell. (Abrol, 2012) [2].

Management

One of the few bee species in New Zealand that is economically maintained and utilized for agricultural pollination is *M. rotundata* (Donovan & Macfarlane 1984) [18]. Due to its combine character and willingness to breed in artificial hives, it is one of the simpler species to handle. In New Zealand, 875, 000 cells were imported between 1971 and 1984, and in the same year, the number of bees was estimated to reach five million. The scientific and industrial research department launched a program to teach beekeepers how to use the species as efficiently as possible. Bee populations subsequently fell after the Department was disestablished in 1992, which put an end to the initiative. Only a few hectares of lucerne were pollinated each year by controlled (Overwintered).

Stingless bee

Stingless bees, classified within the Hymenoptera order, Apidae family, and Meliponini tribe, play a significant role as beneficial insects in pollination and honey production (Cortopassi-Laurino *et al.*, 2006) [11]. Stingless bees are a huge and varied species of eusocial bees, which makes them potential pollinators. They come in a wide range of body sizes, are categorized as small- to medium-sized, and still contain stingers (Quezada-Euán 2018) [54]. Some species have long hairs and a broad, smooth appearance that aids in bringing pollen and other products to the colony (Ramírez *et al.*, 2018) [57]. Certain stingless bee species, particularly those in the genus Melipona, display vibrational activity, necessary to collect the pollen from plants with poricidal anthers like tomatoes and peppers (De Luca and Vallejo-Marín, 2013) [14].

Diversity and Distribution

It is thought that stingless bees, which are 80 million years older than *Apis* bees, first appeared on the African continent before dispersing to other regions of the globe (Crane, 1992; Wilie, 1983) [12, 76]. Their limited capacity to control nest temperature, particularly in cooler climates, limits their habitat to tropical and subtropical areas. According to Muthuraman *et al.* (2013) [46], these bees are mostly found in Australia, Asia, Central, and South America. Over 500 species are included in the eight genera and 15 subgenera that make up the family Meliponinae (Wille, 1983) [76]. The Indian subcontinent is found to be home to eight named species of stingless bees belonging to three genera: *Tetragonula*, *Lepidotrigona*, and *Lisotrigona* (Rasmussen, 2013) [58]. Of the various species, *Trigona* (*Tetragonula*) *iridipennis* is the one that is most frequently observed there (Raakhee and Devanesan, 2000) [56].

Nesting biology

Nesting biology is a highly visible part of stingless bee behavior because nests are conspicuous centers of bee activity and frequently stunning examples of animal construction (Michener, 1974) [42]. There are a lot of elliptical or spherical pots in the nest construction that are used to store honey and pollen. "Cerumen," a mixture of wax released by wax glands and resin obtained from plants, is used to create these pots (Quezada-Euán, 2018) [54]. Stingless bees also known as “dammar bees” in India, use to build their nest with “dammar”, resin of dipterocarp trees along with wax produce from their body (Rasmussen, 2013) [58]. They like to build their nests in dark areas such as hollow logs, tree cavities, cracks and fissures in old buildings, etc., here the entrance usually protrudes as an external tube (Wille, 1983) [76]. *T. iridipennis* was discovered nesting in tree cavities and wall cavities at Dharwad in India (Danaraddi, 2007) [13]. Similar nesting behaviour of *T. iridipennis* was discovered by Roopa (2002) [60], Gajanan *et al.* (2005) [21], and Muthuraman (2006) [47] in Bangalore and Tamil Nadu. *T. bengalensis* was found to have constructed nests in a variety of places, including tree holes, concrete walls, mud walls, iron pipes, and even wash basins in West Bengal, India, according to a recent study done by Kunal *et al.* in 2020 [37].

Management

Meliponiculture refers to the raising or maintenance of stingless bees. They have perennial colonies with hundreds of thousands of workers and are eusocial like real honey bees (Wille, 1983) [76]. Stingless bees' easier-to-handle physiology makes them better adapted to flower pollination than other honey bees because they have mechanisms for gathering pollen and nectar as well as no tendency to sting (Eickwort and Ginsberg, 1980) [20].

In the hollow bamboo tree trunks, *Trigona iridipennis* was raised. We chose bamboo stems that were between 30 and 35 cm in diameter and 80 to 85 cm in length. The bamboo stem is cut in half, and the two parts of bamboo are then tightly connected with ropes. A little opening in the centre of the bamboo stem that has been connected allows bees to enter. The bamboo stem has capped ends on both sides. The knotted log is split into two half, after which the brood chamber is transferred to the bamboo log. The colony finished settling inside the bamboo pole well after two hours. The ends of the bamboo log are shut, the edges are secured with ropes, and both ends are knotted together. The bamboo stick with the bees is brought home and secured beneath the hut's roof. Through the tiny opening left in the centre, the bees inside the bamboo poles begin to exit. Bees smooth the entrance by adding wax from the trees and resin (Propolis) they have collected from them. They reside in intricate colonies. It would be wise for government and other non-governmental organisations to adopt this indigenous approach of domesticating wild bees. Additionally, this will aid in saving the critically endangered stingless bees (Kumar *et al.* 2012) [34].

Crops pollinated by non-*Apis* bees

Crops that are reported to be pollinated by different non-*Apis* bee pollinators are presented in the table 1.

Table 1: Crops with their associated non-*Apis* bee pollinators

Sl. No.	Bee species	Crop/Plant	Family
1.	*Megachile bicolor, M. disjunta, M. flaviceps, M. femorata, M. lanata, Nomia oxybeloides, N. divisus, N. pusilla, Pithitis smaragdula and Xylocopa fenestrata*	Alfalfa *(Medicago sativa)*	Leguminosae
2.	*M. flaviceps* and *M. nana*	Berseem *(Trifolium alexandrium)*	Leguminosae
3.	*Bombus asiaticus* and *B. albopleuralis*	White clover *(T. repens)*	Leguminosae
4.	*Bombus asiaticus and B. albopleuralis*	Red clover *(T. repens)*	Leguminosae
5.	*Megachile lanata, M. bicolor, M. flavipes, M. cephalotes and M. femorata*	Pigeon pea *(Cajanus cajan)*	Leguminosae
6.	*X. pubescens and X. fenestrata*	Sunhemp *(Crotolaria juncea)*	Leguminosae
7.	*X. fenestrata, X. pubescens and Megachile lanata*	Pea *(Pisum sativum)*	Leguminosae
8.	*X. fenestrata, B. albopleurali and Bombus asiaticus*	Sweet potato *(Ipomoea batatas)*	Convolvulaceae
9.	*B. asiaticus*	Eggplant *(Solanum melongena)*	Solanaceae
10.	*Nomioides* spp.	Onion *(Allium cepa)*	Liliaceae
11.	*Nomioides, Megachilids, Andrenids and Halictids*	Field mustard *(Brassica campestris)*	Cruciferae
12.	*Andrena ilerda*	Rape *(Brassica napus)*	Cruciferae
13.	*Andrena ilerda*	Raya *(Brassica juncea)*	Cruciferae
14.	*A. leaena, A. ilerda, Colletes and Halictus* spp.	Taramira *(Eruca sativa)*	Cruciferae
15.	*A. ilerda, Lassiogtossum* spp. *and Pithitis smaragdula*	Cabbage and cauliflower *(B. oteracea)*	Cruciferae
16.	*Anthophora spp, Nomia* spp., *Lassiogtossum* spp. *and Colletes* spp.	Raddish *(Raphanus sativus)*	Cruciferae
17.	*X. fenestrata, X. pubescens Hatictus and* spp. *Nomioides* spp.	Pumpkin and squashes *(Cucurbita spp)*	Cucurbitaceae
18.	*X. fenestrata, X. pubescens and P. smaragduta*	Smooth loofah *(Luffa aegyptica)*	Cucurbitaceae
19.	*Nomia spp, P. smaragduta, Nomioides variegata and Halictids*	Cucumbers *(Cucumis melo)*	Cucurbitaceae
20.	*Lithurgens attratus*	Cotton *(Gossypium* spp.)	Malvaceae
21.	*Nomioides spp, Halictidae and X. fenestrate*	Corriander *(Corraindrum sativum)*	Umbelliferae
22.	*Halictis spp and X. fenestrata*	Saunf *(Foeniculum vulagre)*	Umbelliferae
23.	*Lasiogtossum spp, Sphecoides Hyleaus, Nomioides, Braunsapis and Pfthftis smaragdula*	Carrot *(Dacus carota)*	Umbelliferae
24.	*Andrena spp, Nomioides. Halictus spp and Lasioglossum spp*	Jowain *(Traechyspermum ammi)*	Umbelliferae
25.	*Lasioglossum spp and X. fenestrata*	Orange and lemon *Citrus spp*	Rutaceae
26.	*X. pubescens, X. fenestrata and Megachile lanata*	Guava *(Psidium guajava)*	Myrtaceae
27.	*Xylocopa spp, Megachite spp, Nomia spp and Lasioglossum spp*	Mango *(Mangifera indica)*	Anacardiaceae
28.	*Nomioides, Lasioglossum and Halictus spp*	Pomegranate *(Punica granatum)*	Punicaceae
29.	*Colletes nursei, Lasioglossum spp, CaHulum and Osmia cornifrons*	Apples *(Pyrus malus)*	Rosaceae
30.	*Lasioglossum spp and Xylocopa valga*	Almond *(Pamygdalus)*	Rosaceae
31.	*Xylocopa valga and Nomia* spp.	Cherry *(Pavium)*	Rosaceae
32.	*Xylocopa valga and Nomia* spp.	Pear *(Pcumminis)*	Rosaceae

Crop pollination under protected cultivation

To enhance the yield of fruit with less mechanical damage, greenhouse tomatoes are now pollinated by the neotropical stingless bee *Melipona quadrifasciata* Lepeletier (Del Sarto *et al.*, 2005) [16]. Additionally, stingless bees are important pollinators of greenhouse cucumber crops, increasing fruit weight and productivity (Solange *et al.*, 2008) [67]. In comparison to a control group, strawberries pollinated by stingless bees in greenhouses had higher quality and commercial value (Roselino *et al.*, 2009) [61]. Additionally, compared to self-pollination, Melipona fasciculata Smith's pollination of eggplant (*Solanum melongena* Linn) in greenhouses boosted fruit set by 29.5% and fruit quality (Fruit weight) (Ilva, 2013) [31].

Xylocopa pubescens, a carpenter bee despite having shorter visit durations per flower than honey bees, Spinola is also used to pollinate honeydew melons grown in greenhouses (Cucumis melo Inodorus Group). This is because pollination by both bee species produced fruit with similar masses and numbers of seeds, and X. pubescens pollination increased fruit set three times more than honey bee pollination did (Adi *et al.*, 2007) [3].

Bumble bees have the potential to be sufficient pollinators in open fields and greenhouses since they are significant pollinators of a wide variety of crops, including buzz pollinated crops like blueberries and tomatoes as well as both large-flower and small-flower crops (Desjardins and De Oliveira, 2006; Yankit *et al.*, 2018) [17, 78] Additionally, buzz pollination by *Bombus haemorrhoidalis* Smith in India produces fruits that are bigger, longer, heavier, and healthier, particularly in kiwi fruit (Nayak *et al.*, 2019) [48].

Conclusion and future prospect

Since they constantly protect Mother Nature, pollinators are a precious resource for us. But the community of pollinators was seriously threatened by the development of civilization. Pollination services could be lost as a result of the recent decline in pollinators, especially bees, which could have an effect on the environment and the economy. Therefore, all public lands and natural places should make efforts to maintain a varied range of pollinators a top priority. To ensure the sustainability of our environment, strategies for reducing the various risks associated with pollinator decrease should be explored. By building an environment that is safe for pollinators, priorities should be imposed at the root level. To provide pollination services that help to maintain a sustainable level and reduce the risk of crop loss, both of which serve to prevent ecological harm and loss, it is vital to understand each nation's economic and pollination requirements. Decisions must be made from all sources of bodies, including governmental organisations, non-governmental organisations, and various industrial sectors, for all these activities to save the pollinators' community.

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