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THE FAMILY MEGACHILIDAE (HYMENOPTERA: APOIDEA) IN POLLINATION ECOLOGY- A REVIEW

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ABSTRACT

Family Megachilidae belongs to cosmopolitan family groups, making nests in the soil, and mostly prefer pre-existing cavities such as pithy stems, galls, and dead wood for nesting. Mostly they are solitary, long-tongued, and have pollen-collecting structure scopa present on the ventral side of the abdomen rather than hind legs (mostly in other bees). Genus Megachilid is generally known as leaf cutter and mason bees. Family Megachilidae is characterized by different groups of the bees such as solitary, mason, resin, carder, and leafcutter bees, and are the most important pollinators for agricultural, horticultural, medicinal, and aromatic plants. Female leafcutter bees have a special character to form brood cells by using their mandibles to cut leaves. Family Megachilidae is found throughout the world except for Antarctica, lowland tropical rain forests, deserts, and hilly ecosystems, and 238 species are listed from the Indian region. Our review is based on the significant role of the family Megachilidae and their different adaptive structures and behaviour to enhance their contribution to the pollination ecology.

Key words: Leafcutter bees, Megachilidae, pollination, nesting, non- *Apis*, ecology, foraging, host plant, biology

The world's one-third parts of agricultural pollination are determined by insects and produce seeds and fruits. Order Hymenoptera is generally known for its wide number of species almost 1,55,517 species have been recorded worldwide and more than 10605 species are reported from the Indian region (Chandra et al., 2019; Ahmed et al., 2020) and pollinate most of the agricultural and flowering plants of the world. The manuscript is based on literature and highlights the role of the family Megachilidae in pollination ecology. In addition to this, their different structural adaptation for collecting pollen grains, efficiency, foraging trips, visitation frequency, and pollen carrying capacity have been broadly assorted in this literature. Family Megachilidae consists of 83 genera, 249 subgenera, and 4112 species have been reported globally of which 238 species under 30 genera are recorded from the Indian region (Ascher and Pickering, 2020).

Among all non-*Apis* bees, the family Megachilidae is the second largest family according to the number of species after Apidae and pollinate a large number of cultivated and wild-flowering plants. Non-*Apis* bees are considered as efficient pollinators rather than *Apis* bees under different states because non-*Apis* bees are buzz pollinators, have a long tongue, oligo lectic foraging behaviour, faster-foraging trips, and rate. These characteristics are very helpful in pollination and enhance productivity in the ecosystem. Solitary bees (Megachilidae) have magnificent morphological characters and interactive adaptation so, they are more efficient pollinators in most plants.

Member of the family Megachilidae is the most important pollinator in many agronomic, medicinal, aromatic, and horticultural plants. Their energetic and swimming-like movement inside the flower helps in releasing a large amount of pollen easily from flowers. This family belonged to the cosmopolitan group in which solitary, mason, resin, carder, and leafcutter bees were characterized. The Scopa (pollen-gathering structure) of the solitary bee is restricted to the abdomen rather than the hind leg (mostly in other bees). Mason and leafcutter bees are belonging to the genera Megachilid and reflect the materials from which erected their nest cells. Leafcutter bees are solitary and oligolectic (Robertson, 1929; Cane, 2014), make linear nests from pre-existing cavities, and have a scope on the ventral side of the abdomen which helps in transporting pollen grains. Some bees collect plants and hairs of animals for making their nests, are called carder bees while other bees use plant resin for nesting, known as resin bees. In this family, bees usually feed on pollen and nectar while some other bees forage on collected pollen by other species (Megachilidae), generally known as a kleptoparasite. Parasitic species do not carry a scope for pollen collection.

Diversity and conservation strategies for threatened species of leafcutter bees (Megachilidae) and focused on effective conservation strategies such as creating diversity information (collected from the different climatic regions of Karnataka), richness, and related floral plants was studied. In this study authors documented 4 tribes, 11 genera, 20 subgenera, and 50 species of leafcutter bees and observed that species diversity in the arid zone was higher as compared to other zones. A study data revealed that June- July and September- October are more favourable for the leafcutter bees and recorded as abundantly during these months. While May, August, November, and December exhibit a moderate presence, and the lowest number of bees were noted from January to April because of unfavourable conditions. In ranking order of most abundant species was *Megachile lanta* about 27.01% followed by 14.06% of *M. lerma*, 13.39% of *M. disjucta*, 8.93% of *M. disjuncta*, 5.13% *Lithurgus atratus*, and 4.46 % of *M. bicolor*.They also focused on the conservation of leafcutter bees by using simple practices such as encouraging flowering plants to provide blooms through the budding season, reducing the uses of insecticides, escaping the spraying during blooming and increasing the use of bee's friendly pesticides, providing nesting sites by using drilled wooden blocks & stems and for trap nesting place hollow reeds of *Ipomoea carnea* Jacq. for leafcutter bees.

Parasitisation on leafcutter bees from India was first time recorded and studied highly parasitisation by *Melittobia hawaiiensis* (Hymenoptera: Eulophidae) from 148 out of 173 megachilid cells belonging to four species from 29 nests. The species group of *M. hawaiiensis* has complexes morphological characters. Among the four species of leafcutter bees, *M. lanata* was recorded as the highest parasitized at 54.55% in which 1581 parasitoids emerged from 30 cells with an average of 52.7 each cell. In *M. lerma* 647 parasitoids (72.22%) emerged from 13 cells with an average of 49.76 per cell. All the unidentified species of *Megachile* 515 parasitoid adults emerged from 63.88% of the cells with an average of 57.22 per cell. The lowest parasitisation (33.33%) observed in *M. disjuncta* constructed 163 parasitoid cells from three cells. 100% parasitisation was recorded by only *Mellittobia* from the rest of the 16 nests consisting of 93 cells. 3116 parasitoid adults have emerged from nests with a mean of 33.50 per cell. Overall, an average of 40 *melittobia* adults emerged from a single cell of the nest of *Megachile* sp.

Foraging behaviour and efficiency in pollination of *Osmia cornuta* (Megachilidae) and *Apis mellifera* (Apidae) on "Comice" pear. Extremely self-incompatible (Callan and Lombard, 1978) and a very low yield found in "Comice" pear. *O. cornuta* (Latreille) belongs to the family Megachilidae, is a mason bee and has been recorded as an orchard pollinator. (Asensio, 1984; Torchio and Asensio, 1985; Bosch, 1994 a,b). *O. cornuta* is sturdily fascinated by the flowers of the food plants and nesting sites are situated in 78 to 99% pollen carrying orchards of their host plants. (Marquez et al., 1994; Vicens and Bosch, 2000 a; Maccagnani et al., 2003). A current study shows that *O. cornuta* is the predominant pollinator on pear orchards. Some cultivars found that if increase the distance between orchards and the nesting shelters of *O. cornuta*, found poor productivity. Authors concluded that *O. cornuta* visited more flowers and their visiting frequency was observed by 13.8 minute^{-1}, it was more than *A. melifera* (7.1 to 9.8). Both species of the bees visited the same number of flowers in each tree (6.7 to 7.9). Interaction between stigma and *O. cornuta* was observed by 98.7% and female bees provided pear pollen about 94.4% for their nests. In *A. melifera*, nectar–pollen foragers and nectar foragers were observed by 51.8% and 19.0%, respectively. As a result, found that *O. cornuta* was an exclusively highly efficient pollinator for pear orchards as compared to *A. melifera* and should increase the population of *O. cornuta* in pear orchards for high productivity (Monzon et al., 2004).

Diversity, abundance, and seasonal action of the different species of family Megachilidae from Pantnagar, Uttarakhand state (India) from March, 2013 to April, 2015 were studied. Family Megachilidae bees favour warm climates for flying but still active in the winter season and visit during the blossoming time (Felicioli and Pinzauti, 2008). Data showed that Megachilid bees were found for the whole of the year but during the observation time in the field, bees were not found in the month of February. The authors observed 19 from the field in which 2 species *M. disjuncta* and *M. cephalotes* were active throughout the year. The highest number of species (18) were noted in the month of April, followed by in March and May and, 10 to 12 species were recorded in the months of October and November. Maximum activity of the bees was recorded by two generations (i) in March when an average of the maximum and minimum temperature was 27.4º C to 38.9º C, 13.0º C to 23.4º C and RH% was recorded by 26% to 44% and (ii) In October and November when an average of maximum and minimum temperature was 26.9º C to 30.4º C & 10.2º C to 19.8º C and RH% was 40% to

59%. The lowest activity and least number of the species (0 to 5) were recorded during December to February (winter season) and 2 to 4 species were recorded in the month of July to September (rainy season). The authors recorded 19 different species of Megachilid bees during the field survey in which 7 leafcutter bees that are *M. bicolor*, *M. chlorigaster*, *M. anthracene, M. conjuncta, M. relata, M. studiosa, M. albifrons,* and 6 resin bees viz., *M. hera, M. inepta, M. lanata, M. umbripennis, M. cephalotes, M. disjuncta,* and 6 different bees such as *M. rajasthaniensis, M. tetradenta, M. gathela, M. femorata, M. elizabathae* and *M. binghami* recorded from Pantnagar (Uttarakhand) (Kunjwal et al., 2016).

Male and female bees of *Megachile cephalotes* have different pollen foraging capacity on *Grewia asiatica* (Malvaceae). Besides, their pollination efficiency, pollen-gathering capacity, different morphological characteristics, adaptive structures for pollen collection in *M. cephalotes* (Megachilidae) were also studied by authors. In this study authors selected 458 individuals to 18 species belonging to three different orders in which 13 bees belonging to Hymenoptera, 2 butterflies and one moth from Lepidoptera, and two flies from Diptera, all visited on *G. asiatica* (Phalsa flower). Among all the visitors, the highest floral visitation rate (65%) was recorded by *M. cephalotes* on recipient floral plants. Phalsa flowers attract most of pollinators because they provide energy resources, especially in *Megachile*, *Apis*, and *Xylocopa* (Abrol, 1992). 21 species of bees were recorded on *G. asiatica* from India (Kumar et al., 2017). Different morphological and behavioural factors determine the pollination efficiency in both male and female bees of *M. cephalotes*. The body length of female bees (12.36 to 13.52 mm) is larger than male bees (10.47 to 12.02mm) (Kumar, 2015) and has more scopal hairs than male bees on the ventral side of the abdomen, which helps in a large amount of pollen accumulation (Bzdyk, 2012; Kumar, 2015).

Harder (1983) notified in his study that a long proboscis can absorb a large amount of nectar than short proboscis and female bees of *M. cephalotes* have long proboscis than male bees. Female bees require more pollen collection than male bees because female bees build their nests, collect nectar for their offspring, lay eggs and require energy and nutrients for mating (Feuerbacher et al., 2003). Male and female bees have the same visiting periods on host plants but during visiting period female bees collect more nectar than male bees. The authors are first time documented how abiotic factors such as climatic temperature, relative humidity, speed of airstream, and intensity of sunlight influence the visitation rate, frequency and stay time in both male and female bees. In this study, the authors concluded that visiting rate and pollen deliver capacity of female bees were observed more than male bees. Female bees can fly for shorter distances hence their visiting rate and foraging proficiency increase while male bees fly for a longer distance (Neeman et al., 2006). Male bees are active throughout the day because they perform two major activities i.e., nectar foraging and searching female bees for mating while female bees forage for their offspring and provide nectar that's why female bees are active only during when the floral resources are available (Akram et al., 2019).

Pollination efficiency of *O. cornuta* (Megachilidae) and *Luciana sericata* (green bottle fly) depends on quality, shape, size, weight and colours of strawberry fruits. The authors used 40 cages and each cage contained 6 trees of strawberries. All strawberries plants were exposed by four *O. cornuta* and four *L. sericata* separately, and seven days for two individuals of each species or no pollinators (control). Pollination by the insects increases the production and quality of many agricultural plants, rather than wind and self-pollination (Brittain et al., 2013). Wild bees are considered as most significant group of pollinators and also considered as a chief pollinator on wild flowering plants and crops (Klein et al., 2007) such as watermelon (Kremen et al., 2004), canola (Morandin and Winston, 2005), coffee (Ricketts, 2004), Sunflower (Kremen, 2006) and strawberries (Albano et al., 2009). Most of the species of flies pollinate wildflowers (Larson et al., 2001) and agriculture (Jauker et al., 2012; Rader et al., 2016) and some flies such as *Lucilia sericata* is used for the commercial level in pollination. Diptera is not considered in pollination because of their uncertain biology and pollination activity is still unrevealed. A large number of insects attract by strawberry plants for pollination (Free, 1993; Zaitoun et al., 2006; Kakutani et al., 1993; Wilkaniex and Radajewska, 1996) and produce large quantity and marketable fruits (Hoehn et al., 2008; Klatt et al., 2014). In this study, authors studied the reaction on strawberries of wild bees and fly and hypothesized that (i) practice of both species separately for pollination to increase the quality of strawberry fruits as compared to wind and self-pollination. (ii) use a combination of both species for pollination to increase the quality of fruits because of their functional diversity. As a result, found that *O. cornuta* produced a large number of fruits but small in size with less deformation as compared to without insect pollination while *L. sericata* reduce the deformation of fruits but do not increase weight and size in fruits. By using bees along with flies did not find the better quality of fruits production as compared to bees and flies individually. The discoloration was also observed in fruits by using different insect pollinators in which 10% discoloration was recorded by bees, followed by 11% of flies and 19% of both bees and flies, compared with 26% discoloration by control cages (Herrmann et al., 2019).

Different species of leafcutter bees have different floral preferences for the pollination. Collected pollen samples from nests and compared them with reference pollen slides made by them. They examine 512 brood cells from 373 nests. Each nest had 76.81% brood cells comprised of pollen grains from only one plant species and 19.96% brood cells contained pollen grains from two different species of plants. Only 3.17% of brood cells had pollen from more than two species of plants such as *Justicia*, *Ocimum*, *Ipomoea*, *Abelmoschus* because these bees are not much specific for the particular plant species for nectar. Bees preferred 18 species of flowers for pollen, in which 12 species (highest number) belonged to the Fabaceae family and more than 95% of the food delivered by this family to brood. Most of the pollen grain (67%) recorded from the Fabaceae family pre-dominantly, followed by 11% of Asteraceae, 6% of Lamiaceae, 6% of Malvaceae, 6% of Convolvulaceae, and Acanthaceae accounted for 6% (Pradeepa and Belavadi, 2018).

Leafcutter bees are significant and effective pollinators and making nests in soil, wooden pits, plant stems. They prefer dead snail shells, holes of walls, man-made objects for their nesting sites. They cut 0.25 to 0.5 inches rounded pieces of broad leaves of ornamental plants such as roses, azaleas, ash, redbud, bougainvillea to construct cigar-shaped nests and make numerous cells in the nest; each cell consists of one larva and some pollen grains for their larval nourishment. Then after each cell produces a single bee. Several flowers, fruits, vegetables, and crops are pollinated by leafcutter bees and some bees are used as commercial bees (*Osmia* sp.) to produce a large quantity of production in crops such as blueberries, onion, carrots, and alfalfa. Leafcutter bees are medium in size, mainly extended from 5mm to 24mm, stout body, and black in colour. Female bees transfer pollen grains from anthers to hairs of the abdomen rather than the hind leg. Leafcutter bees are solitary and do not guard their nests violently and their sting is less harmful to the people except holding it. Most of the insects (parasitoids) such as flies, wasps belonging to families Chrysididae, Mutillidae, and beetles belonging to families Rhipiphoridae, Meloidae, and Cleridae and ants. *Crematogaster* sp. attack the nests of leafcutter bees and decrease the aesthetic values of the plants because they cut ornamental plants for making nests hence, considered as a pest and hardly damage the plants. Insecticides do not prevent plants from cutting leaves. Using physical obstacles such as cheesecloths on plants shall be successful prevention from damaging leaves from leafcutter bees.

Study was conducted on life cycle, sex ratio, natural enemies and nesting behaviour of *Megachile maculate* (Megachilidae) in a montane forest in Brazil. They used nesting trap for knowing the natural history of these important bees' groups. They observed 87 nests consisting of seven brood cells in each nest during 27 months. Nesting activity appeared all over the rainy and dry seasons and 344 adults emerged from 87 trap nests. Bees constructed nests in tubular form with different sizes 6, 9, 13, and 16 mm in diameters, in which the majority of the nest's cavities (77%) were 0.9 cm in diameter, consisting of 1 to 11 brood cells. The sex ratio of the bees was observed by 1: 0.42, which was male-biased and the body mass of male bees was lower than female bees. First 6 months of the study there were no nests assembled, representing the no dormancy in *M. maculate*. After the females closed the nests, adults emerged during 3 to 9 weeks. Nesting activity was active throughout the season but adult hatching of their nest constructs during the dry season (7 weeks) longer than a rainy season (5 weeks). Female bees (*M. maculate*) build an average of 5.34 brood cells from 1 to 11. Cells were made by leaves in a rod-shaped and organized in linear sequences. The mortality rate was observed by 26% of which 5% was due to unidentified factors and 18 brood, cells were attacked by three different species of natural enemies; 13 brood cells were attacked by *Coelyoxis* sp. (*Acrocoelioxys*), one brood cell attacked by wasp *Melittobia australica* Girault, 1912 and four brood cells were attacked by *Chrysis* sp. For the first time existence of *M. maculate in* nesting trap was observed (Sabino and Antonini, 2017).

Different types of pollen-collecting mechanisms in the Megachilidae family have been reported. Most of the bees rub their body and scopa with anthers to remove pollen grains and deliver to the body for accumulation with the help of the hind leg. This type of pollen-collecting mechanism is seen in *Osmia cornuta* (Latreille) and *O. lignaria* Say (Megachilidae) (Monzon et al., 2004; Rust and Clement, 1977).

Several distinct types of morphological characteristics are present in bees which make them more efficient pollinators. Most of the bees have hooked hairs present on the fore tarsi of the foreleg which are very specific for the narrow corollas of the flowers. This type of morphological character is seen in *Hoplitis* sp. (Megachilidae) on many host plants (Sedivy et al., 2013). Most of the bee's mouthparts such as stipes, galea, labial and maxillary palpi adapted with hooked hairs for the pollen collection from narrow corollas shaped flowers, this behaviour can be seen on *Heliotropium* (Boraginaceae) by *Haetosmia vechti* (Peters) (Megachilidae) (Gotlieb et al., 2014).

Most of the Megachilidae species collect pollen by "Seesawing" in which scopa directly contact with anthers to remove pollen grains. This mechanism can be seen in *Hoplitis robusta* (Nylander) on *Potentilla* (Rosaceae), *H. zandeni*, *Osmia* sp. on many different host plants and *Pseudoantbidium eximium* (Giraud) on Asteraceae, and *Protosmis minutula* (Perez) on Lamiaceae (Muller, 1996a; Muller, 1996b; Muller and Mauss, 2016). Tapping mechanism is also seen in several species of the family Megachilidae in which bees pick up pollen through a faster up and down motion of the ventral side of the abdomen which directly contacts with the anthers. Tapping mechanism can be seen in *Trachusa, Heriades, Pseudoanthidium, Osmia, Megachile* and *Lithurgus* on Asteraceae family. Rubbing with the face pollen collection behaviour has been observed in *O. pilicornis* Smith (Megachilidae) in which bees rub their face with anthers of the nototribic flowers (stamen and styles are downward) of the *Ajuga reptans* L. (Lamiaceae) to remove a large number of pollen grains. The rasping mechanism also has been observed in *Osmia* sp. (Megachilidae) on *Penstemon* (Plantaginaceae) in which bees constantly jerk their whole body inside and outside to rasp the anthers and scrap pollen from thorax with the help of midleg.

Members of the family Megachilidae play an important role in pollination and are considered efficient pollinators in most agricultural and flowering plants. Megachilids are generally known as leafcutter bees, wood borers, mason bees, resin bees, and cuckoo bees. Leafcutter bees play an important part in the pollination service and provide large productivity. But they reduce the aesthetic values of the plants by cutting leaves for making their brood cells. Due to drought, fire, reduction of survival habitat, destruction of natural habitat, urbanization, enormous uses of the pesticide, these factors decrease the production of crops and flowering plants. In this situation, conservation of the pollinators has appeared major issue. Improve conservation strategies and utilization of good management policies shall increase the diversity of the pollinator. Generating the population of native pollinators resulted in high yields which support the income of the farmers. Enough resources and nesting sites increase the activity of the bees in the habitat. *Ipomoea carnea* Jacq. can use for the conservation of Megachilid bees by making hollow reeds. Most of the bees of this family use different types of pollination mechanisms such as rubbing body or scopa with anthers, presenting supportive structures (hooked hairs on foreleg and mouthparts), seesawing, tapping which help in removing a large number of pollen grains from anthers. Improve management techniques, encourage the flowering plants near the nesting site of the bees, use bee's friendly pesticide and sprayer shall control the declining of the bees.

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AUTHOR CONTRIBUTION STATEMENT

This is a review paper and All the authors contributed during the review of the manuscript. Every author pays full attention to the previous scientific literature. At last, the corresponding author compile all data from all co-authors and prepared and submit the manuscript.

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CONFLICT OF INTEREST

There is no conflict of interest in this study with the earlier studies.

REFERENCES

Abrol D P. 1992. Energetics of nectar production in some strawberry cultivars as a predictor of floral choice by honeybees. Journal of Biosciences 17: 41-44.

Ahmed I, Saini J, Singh L R K, Gupta D, Chandra K. 2020. Insecta: Hymenoptera. Fauna of Haryana, State Fauna Series 24: 189-220.

Akram W, Sajjad A, Ali S, Farooq M, Mujtaba M, Ali M, Ahmad A. 2019. Pollination of *Grewia asiatica* (Malvaceae) by *Megachile cephalotes* (Hymenoptera: Megachilidae): male vs. female pollination. Sociobiology 66: 467-474.

Albano S, Salvado E, Duarte S, Mexia, A, Borges P. 2009. Pollination effectiveness of different strawberry floral visitors in Ribatejo, Portugal: selection of potential pollinators. Advances in Horticultural Science 23: 246-253.

Ascher J S, Pickering J. 2020. Discovery of Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/mp/20q?guide= Apoidea_species.

Asensio De La Sierra E. 1984. *Osmia* (*Osmia cornuta* Latr.) potential pollinator of fruit trees in Spain (Hymenoptera, Megachilidae). Pascal Francis. pp. 461-465.

Bosch J. 1994a. Improvement of field management of *Osmia cornuta* (Latreille) (Hymenoptera, Megachilidae). Apidologie 25: 71-83.

Bosch J. 1994b. The nesting behavior of the mason bee *Osmia cornuta* (Latr) with special reference to its pollination potential (Hymenoptera, Megachilidae). Apidologie 25: 84-93.

Brittain C, Williams N, Kremen C, Klein A. 2013. Synergistic effect of non- *Apis* bees and honey bees for pollination services. Proceeding. The Royal Society B 280: 20122767-20122767.

Bzdyk E L. 2012. A revision of the *Megachile* subgenus *Litomegachile* Mitchell with an illustrated key and description of a new species (Hymenoptera, Megachilidae, Megachilini). Zookeys 221: 31-61.

Callan N and Lombard P. 1978. Pollination effects on fruit and seed development in “Comice” pear[1]. Journal of the American Society for Horticulture Science 103: 496-500.

Cane J H. 2014. The oligolectic bee *Osmia brevis* sonicates *Penstemon* flowers for pollen: a newly documented behaviour for the Megachilidae. Apidologie 45: 678-684.

Chandra K, Saini J and Gupta D. 2019. Fauna of Punjab, Insecta: Hymenoptera: Apoidea (Bees) Fauna of Punjab, State Fauna Series 23: 153-165.

Felicioli A, Pinzauti M. 2008. Pollination by *Osmia* Bees (Hymenoptera: Megachilidae). Encyclopedia of Entomology; Capinera, J L, Ed.; Springer: Dordrecht, The Netherlands 2: 2971-2978.

Feuerbacher E, Fewell J, Roberts S, Smith E and Harrison J F. 2003. Effects of load type (pollen or nectar) and load mass on hovering metabolic rate and mechanical power output in the honey bee *Apis mellifera*. Journal of Experimental Biology 206: 1855-1865.

Free J B. 1993. Insect pollination of crops, 2nd Enlarge. Academic Press, London. 684 pp.

Gotlieb A, Pisanty G, Rozen J, Muller A, Roder G, Sedivy C and Praz C. 2014. Nests, floral preferences and immatures of the bee *Haetosmia vechti* (Hymenoptera: Megachilidae: Osmiini). American Museum Novitates 3808: 1-20.

Harder L D. 1983. Flower handling efficiency of bumble bees: morphological aspects of probing time. Oecologia 57: 274-80.

Herrmann J D, Beye H, de la Broise C, Hartlep H, Diekötter T. 2019. Positive effects of the pollinators *Osmia cornuta* (Megachilidae) and *Lucilia sericata* (Calliphoridae) on strawberry quality. Arthropod Plant Interactions 13: 71-77.

Hoehn P, Tscharntke T, Tylianakis J M, Steffan-Dewenter I. 2008. Functional group diversity of bee pollinators increases crop yield. Proceedings of the Royal Society: Biological Sciences 275: 2283-91.

Jauker F, Wolters V. 2008. Hoverflies are efficient pollinators of oilseed rape. Oecologia 156: 819-823.

Kakutani T, Inoue T, Tezuka T, Maeta Y. 1993. Pollination of strawberry by the stingless bee, *Trigona minangkabau*, and the honey bee, *Apis mellifera*: an experimental study of fertilization efficiency. Researches on Population Ecology 35: 95-111.

Klatt B K, Holzschuh A, Westphal C, Clough Y, Smit I, Pawelzik E, Tscharntke T. 2014. Bee pollination improves crop quality, shelf life and commercial value. Proceedings of the Royal Society: Biological Sciences 281: 20132440.

Klein A M, Vaissière B E, Cane J H, Steffan-Dewenter I, Cunningham S A, Kremen C, Tscharntke T. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society: Biological Sciences 274: 303-313.

Kremen C, Williams N M, Bugg R L, Fay J P, Thorp R W. 2004. The area requirements of an ecosystem service: crop pollination by native bee communities in California. Ecology Letters 7: 1109-1119.

Krunic M D, Brajkovic M M, Mihajlovic L S. 1990. Management and utilization of *Osmia cornuta* Latr. for orchard pollination in Yugoslavia. In VI International Symposium on Pollination 288: 190-193.

Kumar V. 2015. Taxonomic studies on leaf cutter bees (Hymenoptera: Megachilidae) of Karnataka, PhD dissertation, University of Agricultural Science GKVK, Bengaluru. http://krishikosh.egranth.ac.in/handle/1/5810028138

Kumar V, Kumarang K M. 2018. Diversity and conservation of leaf cutter bees (Hymenoptera: megachilidae). Advances in Plant and Agricultural Research 8: 53-54.

Kumar V, Uthappa A R, Srivastava M, Vijay D, Kumaranag K M, Manjunatha N, Rana M, Newaj R, Handa A K, Chaturvedi O P. 2017. Floral biology of *Grewia flavescens* Juss.: an underutilized crop. Genetic Resources and Crop Evolution 64: 1789-1795.

Kunjwal N, Khan M S, Srivastava P. 2016. Species richness and seasonal activity of the leaf cutter and resin bees (Hymenoptera: Megachilidae) at Pantnagar. International Journal of Science and Research 5: 972-977.

Larson B M, Kevan P G, Inouye D W. 2001. Flies and flowers: taxonomic diversity of anthophiles and pollinators. The Canadian Entomologist 133: 439-465.

Maccagnani B, Ladurner E, Santi F, Burgio G. 2003. *Osmia cornuta* (Hymenoptera, Megachilidae) as a pollinator of pear (*Pyrus communis*): fruit-and seed-set. Apidologie 34: 207-216.

Márquez J, Bosch J, Vicens N. 1994. Pollens collected by wild and managed populations of the potential orchard pollinator *Osmia cornuta* (Latr.) (Hym., Megachilidae). Journal of Applied Entomology 117: 353-359.

Monzón V H, Bosch J, Retana J. 2004. Foraging behavior and pollinating effectiveness of Osmia cornuta (Hymenoptera: Megachilidae) and *Apis mellifera* (Hymenoptera: Apidae) on “Comice” pear. Apidologie 35: 575-585.

Morandin L A, Winston M L. 2005. Wild bee abundance and seed production in conventional, organic, and genetically modified canola. Ecological Applications 15: 871-881.

Muller A. 1996. Host-Plant Specialization in Western Palearctic Anthidine Bees (Hymenoptera: Apoidea: Megachilidae). Ecological Monographs 66: 235-257.

Müller A. 1996. Convergent evolution of morphological specializations in Central European bee and honey wasp species as an adaptation to the uptake of pollen from nototribic flowers (Hymenoptera, Apoidea and Masaridae). Biological Journal of the Linnean Society 57: 235-52.

Müller A, Mauss V. 2016. Palaearctic *Hoplitis* bees of the subgenera *Formicapis* and *Tkalcua* (Megachilidae, Osmiini): biology, taxonomy and key to species. Zootaxa 4127: 105-120.

Ne'eman G, Shavit O, Shaltiel L, Shmida A. 2006. Foraging by male and female solitary bees with implications for pollination. Journal of Insect Behavior 19: 383-401.

Pradeepa S, Belavadi V. 2018. Floral preferences for pollen by leaf cutter bees (Hymenoptera: Megachilidae) in Bangalore, India. Journal of Entomology and Zoology Studies 6: 588-596.

Rader R, Bartomeus I, Garibaldi L A, Garratt M P, Howlett B G, Winfree R, Cunningham S A, Mayfield M M, Arthur A D, Andersson G K, Bommarco R. 2016. Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences 113: 146-151.

Ricketts T H. 2004. Tropical Forest fragments enhance pollinator activity in nearby coffee crops. Conservation biology 18: 1262-1271.

Robertson C.1929. Phenology of oligolectic bees and favorite flowers. Psyche 36: 112-118.

Rust R W, Clement S L. 1977. Entomophilous pollination of the self-compatible species *Collinsia sparsiflora* Fisher and Meyer. Journal of the Kansas Entomological Society 50: 37-48.

Sabino W D, Antonini Y. 2017. Nest architecture, life cycle, and natural enemies of the neotropical leafcutting bee *Megachile* (*Moureapis*) *maculata* (Hymenoptera: Megachilidae) in a montane forest. Apidologie 48: 450-60.

Sedivy C, Dorn S, Widmer A, Müller A. 2013. Host range evolution in a selected group of osmiine bees (Hymenoptera: Megachilidae): the Boraginaceae-Fabaceae paradox. Biological Journal of the Linnean Society 108: 35-54.

Torchio P F, Asensio E. 1985. The introduction of the European bee, *Osmia cornuta* Latr., into the US as a potential pollinator of orchard crops, and a comparison of its manageability with *Osmia lignaria propinqua* Cresson (Hymenoptera: Megachilidae). Journal of the Kansas Entomological Society 1: 42-52.

Vicens N, Bosch J. 2000. Pollinating efficacy of *Osmia cornuta* and *Apis mellifera* (Hymenoptera: Megachilidae, Apidae) on 'red delicious' apple. Environmental Entomology 29: 235-240.

Wilkaniec Z, Radajewska B. 1996. Solitary bee *Osmia rufa* L. (Apoidea, Megachilidae) as pollinator of strawberry cultivated in an unheated plastic tunnel. In III International Strawberry Symposium 439: 489-494.

Zaitoun S T, Al_Ghzawi A A, Shannag H K, AI-Tawaha A R. 2006. Comparative study on the pollination of strawberry by bumble bees and honeybees under plastic house conditions in Jordan valley. Journal of Food Agriculture and Environment 4: 237-240.

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