***Review Article***

**Nature’s matchmakers: Insects ~~and their~~ pollination services for crops**

**ABSTRACT**

Insect pollinators play a critical role in global crop production and ecosystem stability. This review highlights the diverse contributions of pollinators, particularly honey bees and wild pollinators, to the enhancement of crop yields and quality. We delve into the economic significance of pollination services, which contribute substantially to global food production and economic value. Honey bees, through their extensive foraging behaviour and superior pollination efficiency, significantly impact the yield and quality of a wide range of crops, including fruits, vegetables, and oilseeds. Furthermore, the role of wild pollinators, such as bumblebees, stingless bees, and various solitary bees, is explored, emphasizing their complementary contributions to commercial pollination systems. The decline in bee populations due to habitat loss and pesticide use underscores the urgent need for sustainable pollinator management practices. This review underscores the importance of conserving both managed and wild pollinators to ensure continued agricultural productivity and food security.

*Keywords*: *Pollination, Animal Pollinators, Honey Bees, Wild Pollinators, Crop Production.*

**1. INTRODUCTION**

Pollination occurs when pollen is transferred from male anthers to female stigmas, either within the same flower or between different flowers. Pollination is a co-evolutionary process that has been unfolding between flowering plants and pollinators for 225 million years. Fossil records show that insects were likely effective pollinators from the time the first flowers appeared. (Leppik, 1960). This process of pollination is crucial for maintaining ecosystems and is fundamental to crop production. It also impacts the economy by improving crop quality and quantity.

Animal pollinators are crucial for the production of 87 global crops, including cocoa (*Theobroma cacao*), kiwi (*Actinidia deliciosa* var. *deliciosa*), passion fruit (*Passiflora edulis*), and watermelon (*Citrullus lanatus*), in over 200 countries. Thirty percent of these crops contribute to global economic food production. In 2005, the global economic value of pollination averaged EUR 153 billion, representing 9.5% of the world's agricultural food production. The leading insect-pollinated crops are vegetables and fruits, each valued at around EUR 50 billion, followed by edible petroleum crops, stimulants, nuts, and spices. One ton of crop production not reliant on insect pollination is valued at about EUR 151, compared to an average of EUR 761 for pollinator-dependent crops. Insect pollination is essential for producing a large number of agricultural products worldwide, including aromatic and medicinal plants such as ~~black cumin (~~*Nigella sativa* linn~~)~~, ~~cumin (~~*Cuminum cyminum* linn~~)~~, ~~anise (~~*Pimpinella anisum* linn~~)~~, ~~sunflower (~~*Helianthus* spp.~~)~~ and ~~coriander (~~*Coriandrum sativum* linn~~)~~. Each season, honey bees, local bees, and flies pollinate 48 of the world's most valuable crops, significantly contributing to the global economy. For instance, in the USA alone, pollination generates USD 16 billion annually, with USD 12 billion attributed solely to honey bees (Khalifa et al., 2021).

In addition to honey bees, there are numerous wild pollinators that play a crucial role in pollination. Several non-bee species, such as the *Elaeidobius kamerunicus* ~~weevil~~ for oil palm and fig wasps for figs, have been introduced outside their native ranges to aid in commercial crop production. Additionally, some fly species are now being commercially reared and managed for crop pollination, with specific rearing protocols available for certain species like Syrphid flies (Radar et al., 2020).

This review highlights the diverse pollinators and their significant role in enhancing crop production. Understanding the effectiveness of different pollinators is vital for supporting agricultural productivity and ensuring food security. Sustainable pollinator management practices are essential for maintaining ecosystem stability and maximizing the economic benefits of pollination services.

**2. MAJOR GROUPS OF INSECT POLLINATORS ~~OF CROPS~~**

**2.1. Hymenoptera**

The order Hymenoptera includes a diverse range of insect groups with various feeding habits. Both wild and managed pollinators significantly contribute to crop pollination, often complementing each other in commercial systems. Bees, the most studied crop pollinators, dominate many pollinator assemblages in both abundance and diversity. Managed bee species include honey bees, stingless bees, *Bombus* species, and a few solitary bees like ~~Alfalfa leaf cutter bees,~~ *Osmia* bees, and Alkali bees. Over 700 wild, unmanaged bee species, both social and solitary, also provide vital crop pollination services (Radar et al., 2020).

**2.1.1. Honey Bees**(mansion sc, name and family)

Honey bee colonies require a constant supply of pollen and nectar to nourish their developing brood and young nest mates, driving forager bees to visit a wide range of flowering plants. Honey bees are valued not only for their products—honey, wax, pollen, royal jelly, venom, and propolis—but also as generalist pollinators. They visit a variety of flowering plants, including many agricultural and horticultural crops. Honey bees possess morphological and biological traits that make them superior pollinators compared to other insects, enhancing their efficiency in pollinating numerous crop plants. (Mussen, 2012). \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Without honey bee pollination, fruit, seed, nut crops, edible oils, stimulants, spices, and pulse crops can suffer up to 90% yield loss, resulting in economic losses of up to 40% (Southwick & Southwick Jr, 1992; Gallai et al., 2009). In mustard crops, honey bees were the dominant flower visitors, with a pod set of 75.41% when pollinated by honey bees compared to 20.18% when pollinating insects were excluded (Goswami & Khan, 2014).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Managed pollination by honey bees has improved various yield and quality parameters, such as fruit size, number of seeds, and fruit shape, along with enhanced pollination services (Free, 1993; Klein et al., 2007). Among the 11 species of eusocial *Apis* honey bees, *Apis mellifera* is the most widely used and studied for its economic and valuable pollination services (Watanabe, 1994; Roubik, 2002). The global beekeeping industry makes honey bees the most important commercial pollinators (Richards, 2001). Supplementing natural pollination with *Apis mellifera* colonies ensures maximum fruit size and yield in crops like pumpkins (Walters & Taylor, 2006). Honey bee pollination services support more than 100 commercially grown crops (Delaplane & Mayer, 2000; Free, 1993; Kearns et al., 1998; McGregor, 1976).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Honey bee pollination greatly enhances the yield and quality of many horticultural crops. Significant fruit crops that benefit from honey bee pollination include apple (Dulta & Verma, 1987), peach (Lee et al., 2005), plum (Sapir et al., 2007), citrus (Malerbo-Souza et al., 2004), and kiwi (Abrol, 1991; Gupta et al., 1998). Honey bees account for 49.88% to 97.32% of the hymenopteran visitors for pear, peach, mango, and litchi (Khan et al., 2010). Honey bee pollination is crucial for the fruit production of pear (Khan & Srivastava, 2010) and strawberry (Khan et al., 2019). Additionally, honey bee pollination helps reduce fruit drop in horticultural crops like apple, peach, plum, and citrus (Dulta & Verma, 1987; Pratap, 2000; Partap et al., 2000). Honey bees, along with bumble bees, are widely used for pollination services in protected cultivation of fruit crops (Zaitoun et al., 2006).\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Scientific evidence shows that bee pollination also improves the yield and quality of vegetable crops like asparagus, carrots, onions, turnips, and more (Deodikar & Suryanarayana, 1972, 1977; Woyke, 1981). Honey bee pollination is known to increase oil content in oilseed crops such as rapeseed and sunflower (Gatoria et al., 2000). Several studies highlight the positive effects of honey bee pollination on seed production and quality in vegetable crops, including cabbage, cauliflower, radish, broadleaf mustard, and lettuce (Abrol, 1991; Pratap & Verma, 1992; Partap & Verma, 1994; Verma & Partap, 1993, 1994).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Another domesticated ~~honey bee species~~, *Apis cerana*, has shown benefits in caged conditions, improving pod set, the number of seeds per pod, and seed weight for ~~radish (~~*Raphanus sativus* ~~L.)~~ plants. Pod setting in three cages was 45%, 42%, and greater than 45%, respectively, compared to open-pollinated conditions (Partap & Verma, 1994). Similar results were found in the fruit setting of cauliflower and cabbage plants pollinated by *Apis cerana*, with 20% and 27% higher productivity, respectively, compared to open-pollinated plants (Verma & Partap, 1994). These bees have also been evaluated as a better alternative for self- and open-pollinated buckwheat (*Fagopyrum esculentum* Moench) (Rahman & Rahman, 2000).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

In addition to domesticated honey bees (*Apis mellifera* and *Apis cerana*), wild honey bee species such as *Apis dorsata* Fabricius and *Apis florea* Fabricius are important pollinators for many plant species, including key field crops. Crane (1990) noted that the dwarf honey bee (*Apis florea*) is an efficient pollinator in orchard and field crops. Higher seed production was observed in ~~onion (~~*Allium cepa* ~~L.)~~ plants visited by *Apis florea* compared to those excluded from their visits (Abrol, 2012). Similarly, in coffee, ~~the wild honey bee~~ *Apis dorsata* was the dominant flower visitor (58% of total) and the major pollinator in South India (Krishnan et al., 2012).

**2.1.2. Bumblebees**(mansion sc, name and family)

Bumblebees are robust, furry, and have relatively larger sized bodies compared to honey bees. Five bumble bee species are commonly used for commercial crop pollination: *Bombus terrestris* Linn (in Europe, North Africa, Asia, and Australasia), *B. occidentalis* Greene (in western North America), *B. ignitus* and *B. lucorum* Linn (in East Asia), and *B. impatiens* Cresson (in North America) (Velthuis & Van Doorn, 2006). Bumblebees' foraging behaviour varies significantly from that of honey bees. They forage more extensively and for longer periods, particularly in the evening, and can forage in cold and rainy weather, unlike honey bees (Willmer et al., 1994; Corbet et al., 1993). Bumblebees start foraging 15–40 minutes earlier than honey bees due to their tolerance to colder temperatures. They also forage faster, visiting more flowers per bee and covering a larger area (Stanghellini et al., 2002). The faster working rate and longer working hours, as well as their ability to collect more pollen makes bumblebees 2-4 times more effective pollinators than honey bees and solitary bees like the alfalfa leafcutter bee (Abrol, 2012). \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Bumble bees contribute to crop pollination by increasing yield and improving fruit quality. They are particularly effective pollinators for crops like ~~kiwifruit (~~*Actinidia deliciosa*~~)~~, ~~sweet pepper (~~*Capsicum annum* Linn~~)~~, and ~~red clover (~~*Trifolium pratense* Linn~~)~~. Bumble bees are crucial pollinators for different crops, including those requiring buzz pollination, such as blueberry and tomato, as well as crops with both large and small flowers, making them suitable for pollination in open fields and greenhouses. Buzz pollination by *Bombus haemorrhoidalis* Smith in India has been shown to produce larger, longer, heavier, and healthier fruits, particularly in kiwi fruit. Bumble bee pollination enhances tomato fruit quality and quantity, increasing the number of fruits per cluster and per plant, as well as fruit length, freshness, breadth, and yield. In sweet peppers, bumble bee pollination results in a higher pollen grain count and greater seed set compared to self-pollination, leading to larger and heavier fruits. Moreover, bumble bees provide significant pollination services to hybrid ~~leek (~~*Allium porrum* Linn~~),~~ resulting in a 25% increase in plant quality and influencing crop price value, estimated at USD 18,007 and USD 17,174 per hectare, respectively. In some instances, wild pollinators outperform honey bees, as observed in apple crops where wild bee species can hold and deposit more apple pollen than honey bees (Khalifa at al., 2021).

**2.1.3. Stingless Bees**(mansion sc, name and family)

Stingless bees, part of the largest eusocial insect tribe Meliponini, include over 600 species globally. These small bees live in eusocial colonies ranging from a few individuals to 60–80 thousand, within various nesting shelters like the ground or man-made plastic pipes, mainly in Neotropical and subtropical regions. They demonstrate greater dietary diversity and more intensive foraging behaviour than honey bees, making them influential in the development of future pollination solutions tailored to specific crops and habitats. They vary significantly in body size, from small to medium, and possess vestigial stings. Some species are large and smooth, with long hairs that aid in transporting pollen and other materials to the colony. The physiology of stingless bees is optimized for flower pollination, featuring structures ideal for collecting pollen and nectar, and their lack of stinging behaviour makes them easier to manage compared to most honey bees. Certain stingless bees, such as those in the genus *Melipona*, exhibit vibration behaviour to extract pollen, which is essential for crops with poricidal anthers, like tomatoes and peppers (Khalifa et al., 2021).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Stingless bees efficiently pollinate many important plant species, including macadamia, coconut, mango, onion, strawberry, loquat, peach, plum, pear, apple, coffee, guava, sunflower, litchi, squash, bitter gourd, sponge gourd, watermelon, cucumber, jackfruit, pigeon pea, coriander, fennel, castor oil, mustard, sesame, and cardamom. In India, *Trigona laeviceps* was the most dominant visitor (35.39% of total visitors) on litchi flowers (Kumar et al., 2013). *Trigona* (*Lepidotrigona*) *terminata* Smith is the most efficient native bee pollinating coffee in Indonesia, with an almost 80% fruit setting rate (Klein et al., 2003). Among oilseed crops, *Plebeia emerina* and *Tetragonisca fiebrigi* are efficient pollen collectors and significant pollinators alongside conventional honey bees (*Apis mellifera*) (Witter et al., 2015). Due to their short foraging range, stingless bees are ideal for protected cultivation (Khan & Yogi, 2017). As buzz pollinators, species like *Melipona fasciculata*, *Trigona carbonaria*, and *Heterotrigona itama* efficiently pollinate tomato, eggplant (Nunes-Silva et al., 2013), sweet pepper (Occhiuzzi, 2000), chili (Azmi et al., 2016), and cucumber crops (Azmi et al., 2017).

**2.1.4. Leafcutter Bees**(mansion sc, name and family)

Megachilid bees, or leafcutter bees, are commonly used solitary bee pollinators for both cultivated and wild plants. Female leafcutter bees primarily collect pollen and nectar for their brood, preferring plants from the Leguminosae family (Kunjwal et al., 2020; Kunjwal et al., 2021). The species *Megachile rotundata*, known as the alfalfa leafcutter bee, has been managed for pollinating alfalfa (*Medicago sativa*) and has significantly increased seed yields in the USA and Canada (Pitts-Singer & Bosch, 2010; Pitts-Singer & Cane, 2011; Bosch & Kemp, 2005). This bee is also used for hybrid seed production in canola (*Brassica napus*) in Canada (Pitts-Singer & Cane, 2011). *M. rotundata* effectively pollinates blueberry (*Vaccinium angustifolium*) and is a suitable substitute for honey bees in caged conditions for carrot (Tepedino, 1996) and canola (Soroka et al., 2001).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Despite its success in North America, the alfalfa leafcutter bee has not achieved similar prominence elsewhere. In Europe, where these bees are native, they remain uncommon as pollinators. Only 0.03% of these bees were reported out of 8,168 pollinating bees in 27 alfalfa fields in Hungary (Móczár, 1961), and none were found among 59 bee species in Spain (Ortiz-Sanchez & Aguirre-Segura, 1991). Additionally, alfalfa crops in France have been unable to support large populations of managed *M. rotundata* (Tasei, 1975).

**2.1.5. Orchard Mason Bees**(mansion sc, name and family)

Orchard mason bees, part of the genus *Osmia* in the family Megachilidae, are effective pollinators for apple orchards in Europe. *Osmia cornuta* is particularly efficient for pollinating almond and apple trees (Vicens & Bosch, 2000). The horn-faced orchard bee, *O. cornifrons*, has successfully provided pollination services in apple orchards in northern and southern Honshu in Japan and has also enhanced tart cherry yields (*Prunus cerasus*) (Biddinger et al., 2013). Additionally, *O. cornuta* improves fruit and seed set in pear orchards (Maccagnani et al., 2003).

The blue orchard bee, *Osmia lignaria*, has doubled sweet cherry (*Prunus avium*) yields in Utah (Bosch et al., 2006). The berry bee, *Osmia aglaia*, effectively pollinates commercial raspberry and blackberry (Rubus) production (Cane, 2008). Approximately 250 nesting structures of *O. lignaria* *propinqua* are sufficient to pollinate an apple orchard on one acre (Torchio, 1985). Over the last decade, 'Bee hotels' or bee nesting shelters have been introduced in various sizes and shapes for the commercial rearing and pollination services of different orchard mason bees worldwide.

**2.1.6. Alkali Bees**(mansion sc, name and family)

The alkali bee (*Nomia melanderi*, family Halictidae) is a native solitary bee of western America, notable for its role in pollinating lucerne (alfalfa) and onion seed production. These soil-nesting bees often form large, gregarious nesting concentrations (Mayer & Miliczky, 1998). They were initially introduced across various parts of the United States to support alfalfa pollination, but in the 1960s, alfalfa leafcutting bees (*Megachile rotundata*) replaced them. Like bumblebees, alkali bees can forage in low sunlight and cooler conditions and visit more alfalfa flowers per bee compared to honey bees (Batra, 1976).

**2.1.7. Other Soil Nesting Mining Bees**(mansion sc, name and family)

The order Hymenoptera includes several soil-nesting mining bees that are important pollinators for various crops. Bees from the genus *Peponapis*, known as squash bees, specifically visit cucurbitaceous crops like squash and pumpkin and are essential pollinators for these plants. Another ~~mining bee,~~ *Habropoda laboriosa*, is economically significant as a pollinator in the USA (Cane, 1993). Additionally, species of *Andrena* are the most numerous bee pollinators in apple orchards in New York (Gardner & Ascher, 2006).

**2.1.8. Blue-banded Bees**(mansion sc, name and family)

Australian native bees, known as blue banded bees, have black bodies with pale yellow thoraxes and blue bands on their abdomens, and belong to the genus *Amegilla*. These bees are widely used for pollination in greenhouse environments, particularly for crops requiring buzz pollination. Blue banded bees are essential pollinators for tomato, chili pepper, and capsicum cultivation across Australia, except in Tasmania (Dollin, 2020). They are an effective alternative to declining bumblebee populations for greenhouse buzz pollination. A total of 282 nesting blue-banded female bees per hectare is enough to provide adequate pollination in greenhouse settings (Hogendoorn et al., 2007). Their buzz pollination eliminates the need for mechanical or hand pollination, increasing greenhouse tomato yields by 20–24% (Bell et al., 2006; Hogendoorn et al., 2006). Additionally, pollination by the blue-banded bee, *Amegilla zonata*, leads to increased seed setting and fruit weight compared to self-pollinated tomatoes (Amla & Shivalingaswamy, 2017).

**2.1.9. Carpenter b~~B~~ees**(mansion sc, name and family)

Large carpenter bees, belonging to the genus *Xylocopa* in the tribe Xylocopini (Apidae: Xylocopinae), inhabit tropical and subtropical regions. Compared to other non-Apis bees, carpenter bees offer numerous advantages in crop pollination due to their broad plant species diet and extended activity seasons. Their ability to buzz-pollinate flowers enhance their role as diverse crop pollinators. However, developing a sufficient breeding program involving genotype selection, controlled mating, and nest foundation is crucial. Carpenter bees are known for nesting in tunnels within hardwood, logs, stumps, or dead tree branches. In India, they remain active year-round, foraging on various flowers during the day and occasionally at night under moonlight. It has been observed that flowers visited by carpenter bees produce odorous nectar, which may serve as a cue for the bees to identify the appropriate flowers (Khalifa et al., 2021).

Carpenter bees are essential for ensuring adequate pollination of several crops, including passion fruit (*Passiflora edulis* f. *flavicarpa*), cucurbits, and other vegetables and fruits, as seen in the Philippines, Brazil, USA, and Malaysia. Yellow passion fruit is effectively pollinated when visited by native bees, particularly carpenter bees. Additionally, using native carpenter bees (*Xylocopa* (*Lestis*)) as an alternative to bumble bees for tomato pollination in greenhouses resulted in females visiting and buzz-pollinating the flowers, producing heavier fruits with more seeds compared to those not pollinated by these bees. The carpenter bee *Xylocopa pubescens* Spinola is also used for pollinating greenhouse-grown honeydew melons (*Cucumis melo* Inodorus Group). Despite having shorter visit durations per flower than honey bees, pollination by both species resulted in similar fruit mass and seed numbers, with *X. pubescens* increasing fruit set three-fold compared to honey bee pollination (Khalifa et al., 2021).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Smaller carpenter bees, such as *Ceratina* species, use soft pith to construct their nests in dead wood, unlike their larger counterparts (Yogi & Khan, 2014). These small carpenter bees are efficient pollinators for many crops, including beans, cowpeas, apples, and coffee, likely contributing to increased agricultural productivity (Eardley et al., 2009). *Ceratina* bees are also key pollinators for Acacia (Sornsathapornkul & Owens, 1998) and teak (Tangmitcharoen & Owens, 1997).

**2.1.10. Wasps ~~as Pollinator~~**(mansion sc, name and family)

Most adult wasps obtain energy from plant-based carbohydrates and nectar from various flowers. While generally predatory towards honey bees and other crop-pollinating bees, wasps help to pollinate many *Ficus* plants. Certain wasp species from the family Agaonidae reside inside fig inflorescences and act as species-specific pollinators. For example, in *Ficus macrophylla*, the winged females of *Pleistodontes froggatti* serve as pollen carriers (Abrol, 2012). Scoliid wasps (Scoliidae) pollinate *Calochilus* orchids (Gumprecht, 1977). Uniquely, Australian thynnine wasps pollinate orchids of the genera *Caladenia* and *Drakaea* by attempting to copulate with the flowers (Phillips et al., 2017, 2020).

**2.2. Diptera**

**2.2.1. Syrphid Flies**(mansion sc, name and family)

Syrphid flies are crucial in agro-ecological systems, providing essential services like biological control of insect pests and pollination (Dunn et al., 2020). They frequently visit flowers of wild plants and agricultural crops, making them the second most important group of pollinators after bees. Although they carry less pollen than most bees, they compensate by visiting more flowers per individual (Larson et al., 2001). Syrphid flies are key pollinators for rapeseed (Jauker & Wolters, 2008; Garratt et al., 2014) and apples (Garratt et al., 2016). The syrphid fly *Eristalis tenax* enhances fruit weight and seed setting in sweet pepper crops under protected cultivation (Jarlan et al., 1996). Honey-bee mimicking drone flies (*Eristalis* spp.) are vital pollinators for strawberries, providing dual benefits of aphid control and enhanced pollination (Albano et al., 2009; Ssymank, 2009; Hodgkiss et al., 2018). Syrphid flies significantly contribute to pollinating both wild and cultivated flowers (Campbell et al., 2010). In New Zealand, *Melanostoma fasciatum* and *Melangyna novaezelandiae* are among the most frequent flower visitors in agro-ecosystems (Morris & Li, 2000).

**2.2.2. Non-syrphid Dipteran Pollinators**(mansion sc, name and family)

Non-syrphid flower-visiting Diptera carry over 84% of the total pollen transferred by Diptera in 33 farmlands in England (Orford et al., 2015). Many of these flies rely on pollen as their primary energy source and thrive on pollen diets. Non-syrphid flies belong to families such as Empididae (Downes & Smith, 1969), Muscidae (Elvers, 1980), Ceratopogonidae (Downes, 1955), and Tabanidae (Magnarelli et al., 1979).

**2.3. Lepidoptera**

Butterflies generally show specificity in their flower choices and exhibit varying degrees of floral constancy. For instance, small skipper butterflies (*Thymelicus flavus*) are known for their high floral constancy (Goulson et al., 1997). The *Meneris tulbaghia* butterfly exclusively pollinates red-flowered *Fynbos* plants (Johnson & Bond, 1994). Although less frequent flower visitors, butterflies can act as primary pollinators for some crops, such as peacock flowers (*Caesalpinia pulcherrima*). The large, scaled wings of butterflies from the family Papilionidae carry *Caesalpinia* pollen and are essential flower visitors for this crop (Cruden & Hermann-Parker, 1979).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_

Moths (Lepidoptera) are major nocturnal pollinators of flowers, though their importance is often overshadowed by the damage caused by their larvae (Macgregor et al., 2015). Gladiolus flowers serve as pollinating hosts for night-flying moths (Noctuidae or Sphingidae) and butterflies (notably one species of Satyridae) (Goldblatt & Manning, 2002).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Hawkmoths are specialized pollinators with long, flexible proboscises for extracting nectar. They feed on and pollinate various plants, including evening primrose (*Oenothera biennis*), some tobacco flowers (*Nicotiana* spp.), and most honeysuckle (*Lonicera*) species (Abrol, 2012).

**2.4. Coleoptera**

Most flower-visiting beetles after landing precisely on flowers, they feed on nectar by chewing the petals. These beetles have structural adaptations like a prolonged prothorax and forward-projecting mouthparts, which help them access nectar deep within the flower, as seen in Cerambycidae beetles (Abrol, 2012).\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

The specificity of plant-pollinator interactions among Coleopteran flower visitors is notable, as they often exhibit host-specific feeding behaviors. For instance, *Annona* spp. flowers emit an odour that attracts dynastid scarab beetles (*Cyclocephala* spp.), which exclusively pollinate these plants. The wide floral chambers of *Annona* flowers facilitate beetle entry to access nectar (Gottsberger, 1989). In some plants, Coleopteran beetles are even primary pollinators before the highly specialized bees. The scarabaeid beetle, *Amphicoma* sp., is considered the primary pollinator for various plant species such as *Anemone coronaria*, *Papaver rhoeas*, *Ranunculus asiaticus*, and *Tulipa agenensis*, outperforming bees like halictid and anthophorid bees as secondary pollinators (Dafni et al., 1990).

**3. Conclusion**

Insect pollinators play a crucial role in maintaining ecological balance by supporting the diversification of key components in terrestrial food chains worldwide. While the focus has often been on a few managed bee species, many solitary and wild bee pollinators, as well as efficient syrphid flies, are underrepresented in studies on pollinator use and conservation. The recent decline in both managed and wild bee populations due to habitat destruction and excessive pesticide use has led to pollination shortages globally. Therefore, it is essential not only to conserve honey bees and bumblebees but also to promote the use and conservation of other solitary and native bee species.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Authors hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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