International Journal of Entomology Research
www.entomologyjournals.com
ISSN: 2455-4758
Received: 09-02-2026, Accepted: 12-03-2026, Published: 27-03-2026
Volume 11, Issue 1, 2026, Page No. 576-585

Insect pollinators: Diversity patterns and economic contributions: A detailed review

Yuvasri*, Dr. Kandibane
Department of Agricultural Entomology, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India

Abstract
Pollination is the process by which pollen is transferred from the male reproductive organs to the female reproductive organs of a flower, ensuring fertilization and seed production in flowering plants**.** Insect pollinators, including bees, butterflies, beetles, and flies, play a significant role in pollination services and thereby maintaining ecosystem health. In exchange for their invaluable pollination services, plants provide pollinators with a variety of rewards, including nectar, pollen, oils, and other nutrient-rich compounds. These rewards are essential for the maintenance and nourishment of these essential contributors to ecosystems. Pollinators are severely impacted by threats such as habitat destruction, the prevalence of monoculture farming, pesticide application, environmental contamination, the spread of diseases, and the adverse effects of climate change. Effective conservation therefore depends on assessing their species diversity, foraging patterns, habitat preferences, and interactions with floral communities.

Keywords: Pollinators, bees, butterflies, hover fly, yield

Introduction

Pollination is one of the vital processes in flowering plants, wherein pollen from the male anther is deposited in the female stigma, facilitating fertilization (Sukumaran *et al*., 2020) [1]. The external vectors to carry their male gametes (contained within pollen) are contributed by wind, water and animals (both vertebrates and invertebrates). Insects are the original pollinators of angiosperms; approximately 90 per cent of the 300,000 flowering plant species worldwide rely on pollinators to mediate their sexual reproduction (Tong *et al.,* 2023; Stephens *et al*., 2023) [2, 3]. Plant-pollinator interaction plays a major role in the economy as well as in maintaining a sustainable ecosystem. The major insect pollinating orders are Hymenoptera (bees, wasp, and ants), Lepidoptera (butterflies, moths, and skippers), Coleoptera (beetles and weevils), Diptera (hover flies, blow flies and bee flies), and Thysanoptera (thrips) (Fig. 1) (Katumo *et al*., 2022; Ollerton, 2017) [4, 5]. Among them, the order, Hymenoptera was the most dominant group of pollinators, visiting 93 per cent of crops, followed by Diptera (72%), and Lepidoptera (54%) (Rader *et al.,* 2020) [6]. Among Hymenoptera, bees represent one of the most diverse, with 20,000 taxa world wide and 796 taxa in India, which were classified into six distinct families namely Apidae (225), Colletidae (31), Melittidae (4), Andrenidae (50), Halictidae (216) and Megachilidae (243) (Pannure and Belavadi, 2019) [7]. The European honey bee, *Apis mellifera* Linnaeus, ranked first in providing highly valued pollination services at a global level for a variety of economically important crops (50% crops). It contributes about 13 per cent of all recorded floral interactions across various ecological networks. (Hung *et al.,* 2018; Kleijn *et al*., 2015) [8, 9]. Crops like sunflower, cotton, apple, almond, coffee, cucurbits, Alfalfa *etc.,* are highly depend on insect pollination. Further, flowers of these plants are gorgeous and luscious to invite a diverse number of insect pollinators for pollination (Khalifa *et al.,* 2021) [10]. Non-*Apis* bee population were increased attention for their vital role in delivering pollination services. Recently, a total of nine Nomiinae bee species, belonging to four genera, were documented in Kerala. These bees were reported to forage on 57 plant species, belonging to 27 families (Athul *et al*., 2025) [11]. Dipteran pollinators, belonging to 71 families, were known to visit over 555 flowering plant species (Orford *et al*., 2015) [12]. Adult hover flies ranked second most important pollinator in the world next to bees (Rader *et al*., 2020) [6]. A total of 131 species of hover flies from the southern Indian subcontinent, grouped into 49 genera across 10 tribes and 3 subfamilies (Ghorpade, 2019) [13]. Butterflies function as essential ecological agents aiding pollination, nearly 141,604 taxa were recorded as flower visitors (Wardhaugh, 2015) [14]. The role of beetles in pollination remains relatively understudied. In India there were around 110 beetles belonging to 15 families that are known to pollinate 80 plants. Among them, the coccinellids play a dominant role in pollination (Paul *et al.,* 2021) [15]. China accounted approximately 30 to 50 per cent of the global economic value derived from pollination, positioning it as the foremost beneficiary among major pollination-dependent nations, including India, the United States, Brazil, Japan, and Turkey (Lautenbach *et al*., 2012) [16]. Over the past five decades, the production of pollinator-dependent crops has surged by 300 per cent, intensifying reliance on pollination for sustaining livelihoods (IPBES, 2016) [17]. In India, a total of 633 insect species, spanning 60 genera across six families, have been identified as key pollinators (Monappa and Sekarappa, 2024) [18]. Totally 51 agricultural and 126 horticultural crops depend on animal pollination. Based on their overall economic value of Rs. 1,29,030.05 crores, oilseeds (Rapeseed and mustard) had a high dependence on insect pollination (34.1%), with an estimated economic value of pollination of Rs. 43,993.08 crores (Chaudhary and Chand, 2017) [19].

Major insect pollinators

The most diverse and abundant pollinators are insects, which belong to five insect orders Lepidoptera is estimated to consist of more than 140,000 species, Coleoptera about 77,300 and Hymenoptera around 70,000 species

(Wardhaugh, 2015) [14]. Diptera and Thysanoptera are the least varied groups of pollinators (Eliyahu *et al*., 2015) [20].

Fig 1: Major flower pollinators

1. Insect pollinators in Hymenoptera

Gaston *et al*. (1991) [21] reported that the order Hymenoptera is the third largest order of insects and includes bees, ants, wasps, and sawflies. Approximately 3,00,000 species are estimated to exist globally, of which more than 1,00,000 have formal descriptions. More than twenty-five thousand species of bees pollinate crop plants worldwide (Sharma *et al.*, 2015) [22].

1.1. Family: Apidae

There are over 5700 species in the Apidae, which includes all of the social bees as well as some solitary and primitively social forms. There are five major groups *viz.,* Anthophorinae, Nomadinae, Apinae, Eucerinae, and Xylocopinae (Udayakumar *et al*., 2022) [23]. Goulet and Huber (1993) [24] mentioned that Apidae bees consist of long-tongued without pygidial or basitibial plates. Queens of highly sociable species lack scopa restricted to metatibia and consisting of fringe of long hairs surrounding large smooth area, thus forming a corbicula. Seven different species of honey bees were reported from Asia *viz*., European honey bee *A. mellifera*, Indian honey bee *Apis cerana indica* (Fabricius), little honey bee *Apis florea* (Fabricius), rock bee *Apis dorsata* (Fabricius) and giant mountain honey bee *Apis laboriosa* (Smith) (Yadav *et al*., 2017) [25]. These honey bees extend their service for pollination. Giant honey bees consist of two species: The enormous honey bee, *A. dorsata*, lives across lowland southern Asia, from Pakistan to the Philippines, Sri Lanka, and the Himalayas. The Himalayan gigantic honey bee, *A. laboriosa*, has adapted to greater altitudes and colder circumstances (Kastberger *et al*., 2024) [26]. Indian honey bee *A. cerana indica*, native to much of Asia, has been utilized for centuries in honey production and as a key contributor to pollination (Koetz, 2013) [27]. *A. florea*, which is otherwise called as red dwarf honey bee, was recognized by its reddish-brown abdomen and small size, and plays a crucial role in pollinating both wild and cultivated plants within its natural habitat (Oldroyd, 2021) [28]. Blue banded bees were effective pollinators that are fossorial and solitary soil nesting creatures. Male bees and female worker bees are floral visitors and collect floral rewards (Jena and Sahoo, 2022) [29]. The western honey bee, *A. mellifera* offers highly valued pollination services for a broad variety of agricultural crops and ranks as the most common single species of pollinator for crops globally (Garibaldi *et al*., 2013) [30]. Approximately, about 20 subspecies of *A. mellifera* have been identified worldwide (Udayakumar *et al.,* 2022) [23].

Stingless bees, part of the Meliponini tribe, are the largest group of eusocial bees with over 500 species. It outnumbers their rival cousins, the honey bees (*Apis* sp.), by 50 times. They have existed for 65 million years, they emerged earlier than *Apis* sp. and their honey boasts higher antimicrobial properties and lower sugar content (Rosli *et al*., 2020) [31]. The genus *Xylocopa* Latreille, 1802, was represented by more than 750 species worldwide, including a total of 45 species from India (Sharma *et al*., 2022) [32].

1.2. Family: Halictidae

Halictidae, commonly known as sweat bees, ranks as the second largest group of bees, with approximately 4,400 species identified across the globe (Ascher and Pickering, 2017) [33]. Goulet and Huber (1993) [24] mentioned that sweat bees lacinia consist of a small lobe separated by membrane from the rest of maxilla. Glossa short to long, pointed. Basitibial plate present in nonparasitic females and many males. Pygidial plate present in females but commonly hidden under tergum 5. Michener (2007) [34] reported that sweat bees comprise four subfamilies; Halictinae, Nomiinae, Nomoidinae and Rophitinae. Nomiinae represented the second largest subfamily within Halictidae comprising 600 described species. The subfamily includes an incredibly diverse group of metallic and non-metallic species, which are largely solitary, except for a few communal nesting species (Batra, 1966) [35]. Pannure and Belavadi (2017) [36] reported a total of 48 species from 13 genera of Nomiinae bees, with 16 species newly recorded in Karnataka, 3 in Andhra Pradesh, 2 in Tamil Nadu, and one each in Kerala and Telangana.

1.3. Family: Formicidae

Ants typically forage on flowers to obtain nectar and other resources, inadvertently pollinating the flowers they visit in the process. A total of 70 ant species, distributed across four subfamilies *viz.,* Formicinae, Myrmicinae, Dolichoderinae, and Pseudomyrmecinae, have been documented as pollinators of 41 plant species belonging to 23 botanical families. Formicinae represents the most dominant group, accounting about 48 per cent (Das and Das, 2023) [37]. Natsume *et al.* (2022) [38] reported the potential role of ant pollination common buckwheat, *Fagopyrum esculentum* (Moench) and found that under the ant-exclusion treatment, the buckwheat plants showed 30 per cent reduction in seed set. *Syzygium species* (Myrtaceae) was grown in the tropical forests of India's Western Ghats. The ant species, *Technomyrmex albipes* (Smith), was reported to be the dominant floral visitor in *S. occidentale* (Bourd) (Kuriakose

et al., 2018) [39]. Bharti *et al*. (2016) [40] provided an updated checklist of Indian ants. India is home to 828 species and subspecies distributed across 100 genera within 10 subfamilies. Myrmicinae ranked highest in species richness with 354 species (42.7%), followed by Formicinae with 241 species (29.1%), Ponerinae with 111 species (13.4%), Dorylinae with 55 species (6.6%), and Dolichoderinae with 30 species (3.6%). The remaining subfamilies collectively contributed 4.2 per cent of the total diversity.

1.4. Family: Vespidae

Vespidae is the cosmopolitan family of predatory wasps. They are pollinators and predators are excellent biocontrol agents (Das and Gupta, 1989) [41]. Indian Vespidae fauna is represented by 288 species belonging to 60 genera and 5 subfamilies (Gawas *et al.,* 2020) [42]. Borchardt *et al.* (2024) [43] expressed that wasps transported and delivered a significant amount of pollen to certain plants. Research involving controlled single-visit deposition demonstrated that the paper wasp, *Polistes fuscatus* (Fabricius) deposited a comparable number of pollen grains.

1.5. Family: Scoliidae

The Scoliidae are solitary aculeate wasps from the Vespoidea superfamily, distributed worldwide. There are over 560 species across 43 genera, grouped into two subfamilies: Pro Scoliinae and Scoliinae (Pham and Achterberg, 2023) [44]. Scoliid wasps are larval parasitoids of scarabaeoid beetles and pollinators of many plants, making them significant in biological control and pollination (Liu *et al.,* 2021) [45].

1.6. Family: Megachilidae

The Megachilidae, recognized for its remarkable diversity, includes leafcutter bees, resin bees, and mason bees. Michener (2007) [34] reported that Megachilidae comprised around 4,000 species found across the globe. It was the largest bee family in India, with 229 species Spread over 24 genera (Mukhtar and Shankar, 2024) [46]. The role of leaf-cutter bees as major pollinators of blueberries, pigeon pea and alfalfa well established (Prashanth and Belavadi, 2015) [47]. Abrol *et al*. (2024) [48] surveyed in Jammu and Kashmir about non-*Apis* insect pollinators and reported 16 species of megachilid bees. Two species of *Megachile hera* (Bingham) and *Megachile bicolour* (Fabricius) contributed major pollination services in Fabaceae, Malvaceae and Cucurbitaceae crops

1.7. Family: Crabronidae

Crabronidae wasps play vital ecological roles, serving not only as pollinators but also engaging in predation and parasitism (Marchiori, 2023) [49]. The Crabronidae is composed of eight subfamilies, with Crabroninae being the most diverse. It encompasses about 100 genera and over 1,500 species globally. Pulawski (2023) [50] documented over 100 species of crabronid wasps from India.

1.8. Family: Agaonidae

In India, 115 species of fig wasps from four families have been documented. Among these, 34 species belong to the family Agaonidae. There are 28 species in four genera that pollinate Ficus trees (Premanik and Dey, 2016) [51]. Female fig wasps have wings, compound eyes, and antennae, while most males are wingless with underdeveloped sensory organs. Males live entirely within figs, whereas females leave to pollinate other fig trees (Sun *et al.,* 2015) [52].

2. Insect pollinators in Lepidoptera

Compared to bees and flies, butterflies and hawkmoths served as relatively minor pollinators across nearly all terrestrial ecosystems (Ollerton, 2017) [5]. The moth group comprised over 127,000 species worldwide. Butterflies, divided into Hesperioidea and Papilionoidea, include 18,000 global species. Butterflies collected relatively little pollen on their bodies, with most of it accumulating near their heads and mouthparts (Barrios *et al*., 2016) [53]. Butterflies that feed on nectar come into contact with pollen grains when visiting flowers, but most are unable to consume it. However, butterflies from the neotropical genera *Laparus* and *Heliconius* have developed a specialized method to extract amino acids directly from pollen, rather than acquiring them by chance during nectar feeding (Castro *et al.,* 2025) [54]. Vairagade (2024) [55] mentioned that India hosts 1,501 species, with notable groups being Hesperiidae (321), Papilionidae (107), Pieridae (109), Nymphalidae (521), and Lycaenidae (443). Tercel *et al.* (2018) [56] recorded that large butterflies were great for wing pollination due to their slow flapping and corrugated wings with prominent veins and scales, allowing for efficient pollen deposition. Nymphalidae, Papilionidae, and Hesperiidae families are effective pollinators owing to their huge body size and movement, whereas Pieridae and Lycaenidae are more restricted to certain environments (Zhang *et al*., 2020) [57].

3. Insect pollinators in Coleoptera

Beetles have been pollinating plants since the early Cretaceous period, significantly contributing to the evolution and variety of flowering plants (Muinde and Katumo, 2024; Bao *et al*., 2019) [58, 59]. Unlike other insect pollinators, flower-visiting beetles are not only pollinators, but also herbivores (Kirmse and Chaboo, 2020) [60]. Beetles were the second most varied group of pollinators, behind Lepidoptera, with approximately 77,000 species observed visiting flowers. Many adult beetles are florivores or feed on pollen, contributing to their significance in pollination (Ollerton, 2017) [5]. Ladybugs played significant roles in plant ecosystems, acting as both predators and pollinators. There are more than 6000 species of coccinellids, recorded world over, of which about more than 400 species have been recorded from India (Sharma *et al*., 2015) [22].

4. Insect pollinators in Diptera

Flies are widely distributed throughout all habitats and biomes, making them one of the most diversified groups, but have received far less attention than bees. Flies are efficient, or better than, bees in pollinating some crops (Ssymank *et al*., 2008) [61]. Most important pollinating families included the Syrphidae, Bombyliidae, Anthomyiidae, Tachinidae, Calliphoridae, Culicidae, Bibionidae, Chironomidae, Empididae, and Cecidomyiidae (Mlynarek, 2022) [62].

4.1. Family: Syrphidae

Hover flies, also called flower flies or syrphids offer dual ecological services, including agricultural pollination and pest management (Dunn *et al*., 2020) [63]**.** Hover fly adults

feed on pollen and nectar, making them the world's second most important pollinators after bees (Rader *et al.,* 2020) [64].

4.2. Family: Calliphoridae

Calliphoridae commonly known as blow flies, blue bottle flies, green bottle flies or carrion flies reported to be an important pollinator in many crops (Dar *et al.*, 2025) [65]. Blow flies appeared to be potential pollinators that are regularly visiting flowering plants (Rangel *et al*., 2023) [66]. They are distributed worldwide, with over 1,000 species and about 150 genera (Brown *et al*., 2009) [67].

4.3. Family: Muscidae

The Muscidae family has more than 5000 known species dispersed over 170 genera (Kutty *et al*., 2008) [68]. In India, the Muscidae family has 263 species divided into 35 genera (Bharti, 2008) [69]. Mitra *et al*. (2010) [70] worked on the diversity of flower visiting flies (Insecta: Diptera) documented 19 species of house flies known to visit or pollinate flowers in India.

Insect pollinators and their economic contribution

Entomophily is estimated to be worth €153 billion annually, accounting for 9.5 per cent of global agricultural output (Gallai *et al*., 2009) [71]. The annual value of global crops directly affected by pollinators ranged from US $ 235 to US $ 577 billion (Potts *et al*., 2016) [72]. Around 73 per cent of the world's crops are dependent on bee pollination, whereas 19 per cent come from flies, 6.5 per cent from bats, 5 per cent from beetles, 5 per cent from wasps and 4 per cent from moths, butterflies and birds (Bashir *et al*., 2015) [73]. Honey bees pollinate the majority of the world's angiosperms, pollinating about 66 per cent of the world's 1500 crop species, accounting for 15-30 per cent of food production. (Ollerton *et al*., 2012) [74]. Khalifa *et al*. (2021) [10] stated that bees contributed to global food security by pollinating a wide range of crops such as fruits, vegetables, oilseeds, legumes *etc*., Five to eight per cent of the world's food production was lost without bee pollination services. The direct contribution of insect pollination to Indian agriculture was 112615.73 crores (USD 22.52 billion) every year, representing 8.72 per cent, besides spillover advantages of improvement in quality features, seed output, breeding efficiency *etc*., (Chaudhary and Chand, 2017) [19]. Insect pollination enhanced average crop yield between 18 and 71 per cent depending on the crop (Bartomeus *et al*., 2014) [75]. The value of non-*Apis* pollinators pollination services was $3.44 billion USD, but honey bees contributed approximately USD 11.68 billion by 2009 in USA (Calderone, 2012) [76]. The annual value of hover fly-mediated pollination has been estimated at $300 billion USD (FAO, 2017) [77].

Insect pollinators in Agricultural crops

Muhammad *et al*. (2020) [78] revealed that *A. mellifera* was an effective pollinator in cotton agro ecosystems with 12 per cent increase in fiber weight and seed set increased 17 per cent in insect pollinated cotton. Khan *et al*. (2025) [79] expressed that insect pollinator on maize yield contribution and the result showed that uncaged crops performed considerably better than caged crops in each metric, including the quantity of grains per cob, cob length, and 1000-grain weight, highlighting the advantages of open pollination (OP). Abrol and Shankar (2015) [80] mentioned that soybean, pigeon pea and other pulses are self-pollinated crops but yield increased by bee pollination have been observed. Navatha and Sreedevi (2012) [81] claimed that castor blooms had twelve different types of insect pollinators, representing seven families and four orders. With six species, Hymenoptera had the most diversity, followed by Lepidoptera with four species. The majority of pollinators (85.13%) were Hymenoptera. The important fodder crop lucerne (*Medicago sativa* Linnaeus) needs, which required pollinators for seed development through tripping mechanism. *Megachile cephalotes* (Smith), *M. hera* (Bingham), and *A. mellifera* were found to be the most efficient pollinators regarding seeds per pod and seed weight (Ejaz *et al.,* 2025) [82]. Islam *et al.* (2022) [83] studied insect pollinator role in rape seed (*Brassica napus* Linnaeus*)* in Bangladesh and reported that plants with inflorescences left exposed to flower visiting insects had a 30.8 per cent greater seed yield compared to those where insect flower visitors were excluded. *Apis* bees were found to be the most abundant pollinator contribute 66.10 per cent. Rani *et al*. (2023) [84] laid out field experiment at Tamil Nadu Agricultural University (TNAU), Coimbatore to investigate the variety and abundance of pollinator fauna on sesamum. The findings identified 19 pollinators from three orders the Hymenoptera, Diptera, and Coleoptera across six families. Among these orders, Hymenoptera was predominant having 15 species with maximum relative abundance. The foraging behaviour of *Apis* sp. was more (4.19 individuals/ m^2/ 5 min) and non - *Apis* sp. was less (1.12 individuals/ m^2/ 5 min). Das and Jha (2019) [85] carried out research in West Bengal on pollination exclusion (PE) in sesame and reported that, in comparison to the pollinator-excluded condition, the seed production increased by 49.92 per cent and 35.23 per cent in open and honey bee pollination, respectively.

Padhy *et al.* (2024) [86] reported eighteen different pollinators associated with sunflower. The Indian honey bee, *A. cerana indica* was the most dominant hymenopteran pollinator, followed by the rock bee *A. dorsata* from family Apidae. The diversity indices showed the mid flowering stage attracted the most diversified group of pollinators. Sajjanar and Thippaiah (2021) [87] conducted an experiment at University of Agricultural Sciences, Raichur and found that the plots of hand + open pollinated sunflower heads produced the highest yield of sunflower hybrid seeds (1284.25 kg / ha), followed by the plots exposed with four colonies of *A. cerana indica*. The highest oil content (36.85%) and benefit cost ratio (2.22) was recorded in plot treated with three colonies of *A. cerana indica* per acre. Shultz *et al*. (2022) [88] supported that honey bee (*A. mellifera*), carpenter bee (*Xylocopa micans* Lepeletier), earwig (*Doru taeniatum* Dohrn), bumble bee (*Bombus* sp.) and hover fly (*Toxomerus politus* Say) were known to consume sorghum pollen acting as a pollinator in sorghum. Siede *et al*. (2021) [89] stated that by using bees to pollinate sorghum, the crop's seed production increased by 2.5 times and its seed quantity increased in unfavourable weather conditions.

Insect pollinators in Horticultural crops

Hay crops generated from bee pollinated seeds covered around 40 million acres. Approximately 6 million acres were planted to grow fruits, vegetables, and nuts rely on insect pollination. These plants constituted around 15 per cent of the human diet (McGregor, 1976) [90]. Elisante *et al*.

(2020) [91] investigated the effects of excluding pollinators on common beans (*Phaseolus vulgaris* Linnaeus) in Tanzania. The yield research showed that open-pollinated beans produced 1,478 kg per hectare, whereas self-pollinated beans produced 681 kg per hectare, showing the essential role of pollinators in enhancing crop yields. Yogapriya *et al*. (2018) [92] assessed pollinator diversity in bittergourd flowers at Tamil Nadu and documented 51 pollinator species, including 19 Hymenopteran species, 15 Lepidopteran species, 7 Dipteran species, and 6 Coleopteran species. The most prevalent pollinator was *Tetragonula iridipennis* (Smith), which was followed by *A. florea*, *Halictus* sp., and *A. cerana indica*. Kaushik *et al*. (2012) [93] reported that among the insects frequently visiting banana inflorescences; honey bees (*A. cerana indica*, *A. mellifera*, and *A. dorsata*) were the most dominant visitors, comprising 77.50 per cent of the total. Wasps (*Polistes hebraeus* and *Vespa orientalis*), followed with a visitation rate of 15.53 per cent. Charan *et al*. (2023) [94] documented pollinator diversity in yard long bean in Rajasthan and identified 20 species of insect foragers from Hymenoptera and Diptera. The most abundant order was Hymenoptera, and the most abundant family was Apidae. Brinjal (*Solanum melongena* Linnaeus) is an important solanaceous crop with a cross-pollination rate as high as 48 per cent. A total of nineteen pollinators belonging to Hymenoptera (84.16%) and Diptera (18.16%) were attracted to brinjal flowers. (Mondal *et al*., 2022) [95]. In snake gourd, Nymphalidae and Papilionidae families of butterflies were reported as major pollinators (Balachandran *et al*., 2017) [96]. According to Ramirez *et al*. (2004) [97], coconut self-pollination by geitonogamy produced almost 19 per cent of the fruit set, but cross-pollination (xenogamy) was the most important contribution up to 30 per cent. Anemophilous cross-pollination only accounted for 10 per cent of fruit set. Entomophily appeared as the primary method of pollination. Halder *et al.* (2024) [98] studied the role of pollinators in pointed gourd (*Trichosanthes dioica* Roxb) and found that fruits pollinated by beetles were longer (6.88 cm), width (2.83 cm), fruit weight (22.63 g), and lesser number of seeds (16.75) than the hand-pollinated fruits. Singh (2020) [99] reported *A. cerana indica was* found to be the most efficient pollinator of guava flowers in Nagaland, followed by *A. dorsata*. The highest performance of *A. cerana indica* coincided with the peak of anthesis. Kumari *et al*. (2014) [100] studied pollinator diversity on mango trees at Andhra Pradesh and reported pollinators belonged to the orders Diptera and Hymenoptera. The important pollinators were *A. dorsata, A. florae, A. cerana indica*, *Coccinella septumpunctata* (Linnaeus), *Musca nebulo* (Fabricius) and butterflies. Honey bee was found to be the major pollinator contributing 30 per cent.

Umesh (2020) [101] studied on insect pollinator diversity in pumpkin during *Kharif* 2019 at Rajasthan and recorded that among honey bees, the most prevalent one was *A. dorsata* (67.40%), which was followed by *A. florea* (14.28%). *A. dorsata* activity was an important pollinator in pumpkin to obtain more yield under open conditions. Longkumer *et al*. (2024)[102] studied pollinator role in pumpkin at Nagaland and expressed that Indian bees were the most active pollinator based on foraging behaviour and pollination efficiency. Plots caged with *A. cerana indica* had the greatest fruit setting rate (77.5%), greater fruit length (20.17 cm), and healthy fruit percentage (89.73%), as well as increased seed count (162) and seed weight (15.63 g). Thakur and Rana (2008) [103] studied the role of insect pollinators in cucumber during Summer 2007 at Solan, Himachal Pradesh and recorded that fruit set increased significantly, with hand pollination having the greatest rate (75.68%), followed by honey bee (74.96%) and open (62.09%) pollination. The insects visiting blooms of cucumber included, *Xylocopa vulga* (Gerstaecker), *A. cerana indica, A. mellifera, Bombus impatiens* (Cresson), *Megachile atrata* (Smith) and *Eristalis arbustorum* (Linnaeus). Among these insect's honey bees were the major pollinators of cucumber (Hanif *et al*., 2022) [104]. Singh *et al.* (2017) [105] studied pollinator diversity in okra flowers at Chandigarh, India. and recorded 10 major insect pollinators *i.e., Eristalis* sp., *Pieris canidia* (Sparrman), *Papilio demoleus* (Linnaeus), *Ropalidia flavolineata* (Cameron), *Polistes hebraeus* (Fabricius), *A. dorsata*, *A. cerana indica*, *A. florea*, *A. mellifera* and *Megachile* sp. Subbanna *et al.* (2024) [106] evaluated okra yield related parameters of insect pollinated flowers in mid Himalayan region, and reported that superior quality fruits with better capsule length (17.4–20.9 cm), capsule girth (6.56–7.84 cm), seeds/capsule (51.4–60.6), test weight of 100-seeds (7.05–8.38 g) and even the seed yield (1.86–3.04 tonnes/hectare) than closed control and hand pollination.

Insect pollinators and weed flora

Weeds provide floral rewards which increase pollinators chances of surviving. Weed species play a significant role in sustaining the populations of social and wild bees that provide vital pollination services for the maintenance of biodiversity and enhancing crop yields (Deeksha *et al*., 2022) [107]. Insect pollinated weeds are also frequently found in agricultural ecosystems. The ecological significance of weed populations for pollinator biodiversity is essential (Benvenuti, 2024) [108]. Kleiman *et al*. (2021) [109] investigated the relationship between weeds and insect pollinators in a mango field in the United States. The fruit production in the weedy condition was much higher than that in the weed-free ecosystem, and the weedy mango trees had significantly more pollinators.

Role of colour and shape of flower in insect pollinator preference

Flowers attract pollinators through various features, based on their colour, shape, flower size, fragrance, nectar and pollen offerings (Shrestha *et al.,* 2013) [110]. The attributes of pollinators, such as their body size, unique morphology, behavioural tendencies, and foraging preferences, profoundly shape the dynamics of plant-pollinator relationships. For instance, bees, with their highly specialized mouthparts and meticulous grooming habits, are exceptionally adept at gathering and transferring pollen. On the other hand, butterflies and moths, equipped with their elongated and slender proboscises, are remarkably suited for extracting nectar from deeply structured floral tubes (Tekulsky, 2023) [111].

Pollinators rely on floral rewards, such as nectar and pollen, as their primary food sources (Vaudo *et al*., 2020) [112]. Nectar is rich in carbohydrates and amino acids whereas pollen provides essential proteins and lipids (Borghi and Fernie, 2017) [113]. Reverte *et al.* (2016) [114] stated that pollinators rely heavily on colour to identify flowers. Bees were attracted by purple flowers, whereas ants preferred

ultra violet yellow and green blooms. UV yellow blooms attracted primarily wasps and dipterans. Coleopterans were drawn to two colours: white and yellow flowers. Wang *et al.* (2024) [115] stated that disk/bowl and flag flowers were preferred by honey bees. Solitary bees favoured horizontal, lip, or flag flowers. Lepidoptera favored horizontal, funnel-shaped flowers or flower heads, while Diptera most often visited upward-facing flower heads. Beetle-pollinated flowers have broad, flat shapes similar to plates or bowls, offering a convenient landing spot and often serving as a sheltered resting area for the insects (Weber *et al*., 2020) [116].

Table 1: Insect pollinators and flower characters

Pollinator	Preferred Colours	Preferred Flower Shapes	Key Traits	References
Bees	Blue, Purple, Yellow, Ultraviolet (UV)	Complex, tubular, or disc-shaped	Need a landing platform; attracted by "nectar guides" (UV patterns).	USDA Forest Service: Pollinator Syndromes [117]
Butterflies	Red, Pink, Orange, Yellow, Purple	Flat-topped, clustered, or tubular with wide rims	Use a long proboscis; require a sturdy landing pad for feeding.	Ujjawala *et al*., (2025) [118]
Flies	White, Cream, Yellow, Green	Simple, open, shallow, or bowl-shaped	Short mouthparts require easy nectar access.	Garcia *et al.,* (2022) [119]
Beetles	White, Cream, Dull Green, Pale	Large, bowl-shaped, or flat/disc-shaped	Clumsy fliers needing a broad landing area; often feed on pollen.	USDA Forest Service: Beetle Pollination [120]

Weather parameters and their role in pollinator activity

Temperature, relative humidity, solar radiation, and wind all had a significant impact on honey bee activity. As temperature rise, honey bees increased their activity while decreasing their fighting behaviour in response to higher relative humidity and stronger wind speeds. Honey bee activity was lowered when solar radiation levels were lower because there was less morning sunshine or less visibility in cloudy conditions (Karbassioon *et al.,* 2023) [121]. Ansari *et al.* (2017) [122] reported that climatic factors like temperature, rainfall, relative humidity, and cloudiness showed a negative correlation with hoverfly abundance. Gautam and Kumar (2018) [123] revealed that foraging activity of pollinators were significantly impacted by temperature. Most pollinators relied on powered flight to travel between flowers, and rainfall affected their flight performance in various ways (Lawson and Rands, 2019) [124]. Turshak *et al.* (2023) [125] stated the influence of primary weather factors *viz*., temperature and wind speed on butterfly abundance, both showing an inverse relationship higher levels lead to fewer butterflies.

Decline of insect pollinators

Pollinator populations around the world have been declining at an alarming rate in recent decades due to habitat loss, pesticide use, pests, pathogens, pollution, and climate change, which result in reduced pollination services and disturbs ecosystem (Fig.2) (Dainese *et al*., 2019) [126].

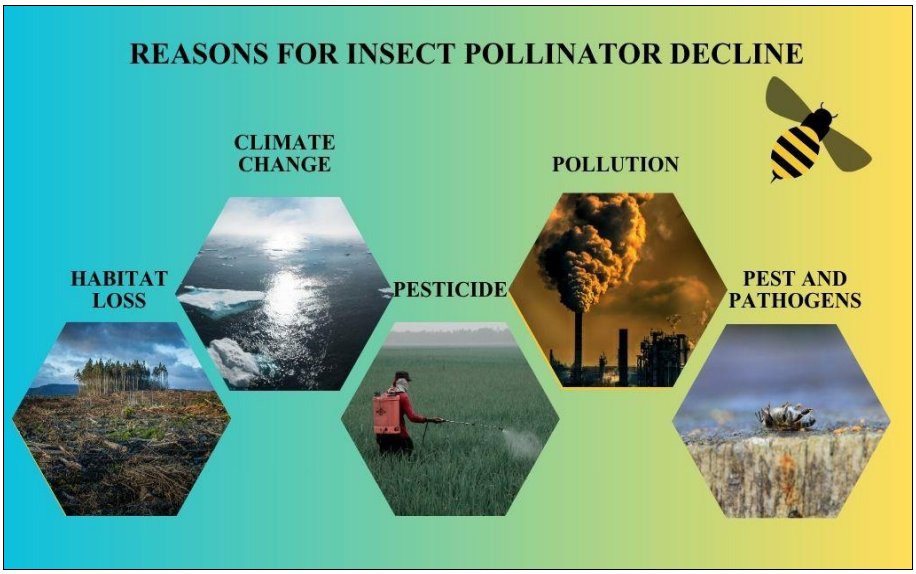

Fig 2: Major threat for pollinators

Conclusion

Cross-pollinated and often cross-pollinated crops in agriculture and horticulture largely depend on insect pollinators for successful pollination. Without the visits of insect pollinators, these crops are unable to transfer viable genetic material from the parent generation to subsequent generations. Moreover, greater diversity of pollinators within an ecosystem enhances crop yield and overall productivity. Conservation efforts for insect pollinators should be undertaken by studying the diversity of pollinator species, their foraging behaviours, habitat preferences, and interactions with various floral communities. (Nath *et al*., 2023, Brunet and Fragoso, 2024) [127, 128].

References

1. Sukumaran A, Khanduri VP, Sharma CM. Pollinator-mediated self-pollination and reproductive assurance in an isolated tree of *Magnolia grandiflora* L. Ecological Processes,2020:9(1):45.
2. Tong ZY, Wu LY, Feng HH, Zhang M, Armbruster WS, Renner SS, *et al*. New calculations indicate that

90% of flowering plant species are animal-pollinated. National Science Review,2023:10(10).
3. Stephens RE, Gallagher RV, Dun L, Cornwell W, Sauquet H. Insect pollination for most of angiosperm evolutionary history. New Phytologist,2023:240(2):880–891.
4. Katumo DM, Liang H, Ochola AC, Lv M, Wang QF, Yang CF. Pollinator diversity benefits natural and agricultural ecosystems, environmental health, and human welfare. Plant Diversity,2022:44(5):429–435.
5. Ollerton J. Pollinator diversity: distribution, ecological function, and conservation. Annual Review of Ecology, Evolution, and Systematics,2017:48(1):353–376.
6. Rader R, Cunningham SA, Howlett BG, Inouye DW. Non-bee insects as visitors and pollinators of crops: Biology, ecology, and management. Annual Review of Entomology,2020:65(1):391–407.
7. Pannure A, Belavadi VV. Status and Diversity of Pollinators in India – a Case Study for Conserving Non-*Apis* Bees. ENVIS Newsletter, Zoological Survey of India, Kolkata,2019:25:1–4.
8. Hung KLJ, Kingston JM, Albrecht M, Holway DA, Kohn JR. The worldwide importance of honey bees as pollinators in natural habitats. Proceedings of the Royal Society B: Biological Sciences,2018:285(1870):20172140.
9. Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, *et al*. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications,2015:6(1):7414.
10. Khalifa SAM, Elshafiey EH, Shetaia AA, Wahed AAAE, Algethami AF, Musharraf SG, *et al*. Overview of bee pollination and its economic value for crop production. Insects,2021:12(8):688.
11. Athul CS, Vishnu AV, Prakash AS, Bijoy C, Shaji EM. A checklist of Nomiinae (Hymenoptera, Halictidae) from Kerala, India: new distributional and floral association records. Journal of Insect Biodiversity and Systematics,2025:11(3).
12. Orford KA, Vaughan IP, Memmott J. The forgotten flies: the importance of non-syrphid Diptera as pollinators. Proceedings of the Royal Society B: Biological Sciences,2015:282(1805):20142934.
13. Ghorpade K. Hover-flies (Diptera: Syrphidae) recorded from "Dravidia," or Central and Peninsular India and Sri Lanka: An annotated checklist and bibliography. Indian Insects, CRC Press,2019:325–388.
14. Wardhaugh CW. How many species of arthropods visit flowers? Arthropod-Plant Interactions,2015:9(6):547–565.
15. Paul A, Debnath R, Karmakar S, Roy R, Pal S, Mitra B. A review on beetle–pollination in India. Journal of Advanced Scientific Education and Research,2021:2(1):186–213.
16. Lautenbach S, Seppelt R, Liebscher J, Dormann CF. Spatial and temporal trends of global pollination benefit. PLoS One,2012:7(4):e35954.
17. IPBES. Summary for policymakers of the assessment report on pollinators, pollination and food production. United Nations Environment Programme,2016:11.
18. Monappa NB, Sekarappa B. Density, abundance and diversity of insect pollinators at agro-ecosystems of Kodagu District, Karnataka, India. Asian Journal of Biological and Life Sciences,2024:13(2):385.
19. Chaudhary OP, Chand R. Economic benefits of animal pollination to Indian agriculture. Indian Journal of Agricultural Sciences,2017:87(9):1117–1138.
20. Eliyahu D, McCall AC, Lauck M, Trakhtenbrot A, Bronstein JL. Minute pollinators: The role of thrips (Thysanoptera) as pollinators of point leaf manzanita, *Arctostaphylos pungens* (Ericaceae). Journal of Pollination Ecology,2015:16:64.
21. Gaston KJ. The magnitude of global insect species richness. Conservation Biology,1991:5:283–293.
22. Sharma HD, Khound A, Rahman S, Rajkumari P. Significance of honey bee as a pollinator in improving horticultural crop productivity in N.E. Region, India: A review. Asian Journal of Natural and Applied Sciences,2015:4(1).
23. Udayakumar A, Subaharan K, Shivalingaswamy TM. Diversity of bee pollinators – global and Indian perspective. Indian Journal of Plant Genetic Resources,2022:35(3):397–400.
24. Goulet H, Huber JT. Hymenoptera of the world: An identification guide to families. Canadian National Collection of Insects,1993:668.
25. Yadav S, Kumar Y, Jat BL. Honeybee: Diversity, castes and life cycle. Industrial Entomology,2017:5–34.
26. Kastberger G, Ebner M, Hotzl T. Giant honeybees (*Apis dorsata*) trade off defensiveness against periodic mass flight activity. PLoS One,2024:19(4).
27. Koetz AH. Ecology, Behaviour and Control of *Apis cerana* with a Focus on Relevance to the Australian Incursion. Insects,2013:4(4):558–592.
28. Oldroyd BP. Dwarf honey bees (*Apis* (Micrapis)). In Encyclopedia of Social Insects. Springer International Publishing, Cham,2021:333–339.
29. Jena M, Sahoo S. Blue banded bee, *Amegilla* spp.: A potential pollinator in pollination of crop plants. AgriCos e-Newsletter,2022:3(6):4–8.
30. Garibaldi LA, Dewenter IS, Winfree R, Aizen MA, Bommarco R, Cunningham SA, *et al*. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science,2013:339(6127):1608–1611.
31. Rosli FN, Hazemi MHF, Akbar MA, Basir S, Kassim H, Bunawan H. Stingless bee honey: Evaluating its antibacterial activity and bacterial diversity. Insects,2020:11(8):500.
32. Sharma S, Sharma G, Joshi N. Species diversity of genus *Xylocopa* (large carpenter bee) (Insecta: Hymenoptera: Apoidea) and their floral resources in district Dehradun, Uttarakhand, India. Annals of Entomology,2022:40(2).
33. Ascher JS, Pickering J. Discover Life bee species and world checklist (Hymenoptera: Apoidea: Anthophila). Discover Life, 2017.
34. Michener CD. The bees of the world. Johns Hopkins University Press; 2007.
35. Batra SW. Nests and social behavior of halictine bees of India (Hymenoptera: Halictidae). Indian Journal of Entomology,1966:28:375.
36. Pannure A, Belavadi VV. An updated distributional checklist of bees of the subfamily Nomiinae (Hymenoptera: Apoidea: Halictidae) with new records from South India. Entomon,2017:42(4):311–328.
37. Das S, Das A. Ants are more than just curious bystanders to some flowers—they act as significant pollinators. Frontiers in Insect Science,2023:3:1145761.

38. Natsume K, Hayashi S, Miyashita T. Ants are effective pollinators of common buckwheat *Fagopyrum esculentum*. Agricultural and Forest Entomology,2022:24(3):446–452.
39. Kuriakose G, Sinu PA, Shivanna KR. Ant pollination of *Syzygium occidentale*, an endemic tree species of tropical rain forests of the Western Ghats, India. Arthropod-Plant Interactions,2018:12(5):647–655.
40. Bharti H, Guenard B, Bharti M, Economo EP. An updated checklist of the ants of India with their specific distributions in Indian states (Hymenoptera, Formicidae). ZooKeys, 2016.
41. Das BP, Gupta VK. The social wasps of India and the adjacent countries. Association for the Study of Oriental Insects, Gainesville, FL; 1989.
42. Gawas SM, Kumar PG, Pannure A, Gupta A, Carpenter JM. An annotated distributional checklist of Vespidae (Hymenoptera: Vespoidea) of India. Zootaxa,2020:4784(1):1–87.
43. Borchardt KE, Holthaus D, Mendez PAS, Toth AL. Debunking wasp pollination: Wasps are comparable to bees in terms of plant interactions, body pollen and single-visit pollen deposition. Ecological Entomology,2024:49(4):569–584.
44. Pham PH, Achterberg CV. Taxonomic study of the tribe Campsomerini (Hymenoptera, Scoliidae) from northern Vietnam, with the description of a new species and a checklist of Vietnamese scoliid wasps. Deutsche Entomologische Zeitschrift,2023:70(2):369–385.
45. Liu Z, Yang SJ, Wang YY, Peng YQ, Chen HY, Luo SX. Tackling the taxonomic challenges in the family Scoliidae (Insecta, Hymenoptera) using an integrative approach: A case study from Southern China. Insects,2021:12(10):892.
46. Mukhtar Y, Shankar U. Expanding Megachile diversity: First record of nine *Megachile* species (Hymenoptera: Megachilidae) from Jammu, India and the broader North-Western Himalayas. Oriental Insects,2024:1–25.
47. Prashanth K, Belavadi VV. Role of flower visitors in pollination and pod set of pigeonpea, *Cajanus cajan* (L.) Millspaugh. Paper presented at the 2nd Api Eco Flora Conference, University of Rome, Italy, 2015.
48. Abrol DP, Chatterjee D, Ghosh S, Namin SM, Son M, Jung C. Association of wild pollinators of Megachilid bees (Hymenoptera: Megachilidae) and their host plants in diverse agroecosystems in Jammu, India. Journal of Asia-Pacific Entomology,2024:27(4):102297.
49. Marchiori C. Mini review of the family Crabronidae (Insecta: Hymenoptera) sand wasps: Natural history, behaviour and taxonomy. Qeios, 2023.
50. Pulawski WJ. Catalogue of Sphecidae sensu lato. California Academy of Sciences, 2023.
51. Premanik A, Dey D. An annotated checklist of the fig wasps (Hymenoptera: Chalcidoidea) of India. Oriental Insects,2016:50(2):84–94.
52. Sun BF, Li YX, Jia LY, Niu LH, Murphy RW, Zhang P, *et al*. Regulation of transcription factors on sexual dimorphism of fig wasps. Scientific Reports,2015:5(1):10696.
53. Barrios B, Pena SR, Salas A, Koptur S. Butterflies visit more frequently, but bees are better pollinators: The importance of mouthpart dimensions in effective pollen removal and deposition. AoB Plants, 2016:8.
54. Castro ECPD, McPherson J, Jullian G, Mattila AL, Bak S, Montgomery SH, *et al*. Pollen-feeding delays reproductive senescence and maintains toxicity of *Heliconius erato*. Peer Community Journal,2025:5.
55. Vairagade SP. Butterfly diversity in different forest areas of India: Review. International Journal of Creative Research Thoughts,2024:12(2).
56. Tercel MP, Veronesi F, Pope TW. Phylogenetic clustering of wingbeat frequency and flight-associated morphometrics across insect orders. Physiological Entomology,2018:43(2):149–157.
57. Zhang HH, Wang WL, Yu Q, Xing DH, Xu ZB, Duan K, *et al*. Spatial distribution of pollinating butterflies in Yunnan Province, Southwest China with resource conservation implications. Insects,2020:11(8):525.
58. Muinde J, Katumo DM. Beyond bees and butterflies: The role of beetles in pollination system. Journal for Nature Conservation,2024:77:126523.
59. Bao T, Wang B, Li J, Dilcher D. Pollination of Cretaceous flowers. Proceedings of the National Academy of Sciences,2019:116(49):24707–24711.
60. Kirmse S, Chaboo CS. Flowers are essential to maintain high beetle diversity (Coleoptera) in a Neotropical rainforest canopy. Journal of Natural History,2020:54(25–26):1661–1696.
61. Ssymank A, Kearns CA, Pape T, Thompson FC. Pollinating flies (Diptera): A major contribution to plant diversity and agricultural production. Biodiversity,2008:9(1–2):86–89.
62. Mlynarek JJ. Diptera pollinators. Current Biology,2022:32(7):R305–R306.
63. Dunn L, Lequerica M, Reid CR, Latty T. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): Pollinators and biological control agents. Pest Management Science,2020:76(6):1973–1979.
64. Rader R, Cunningham SA, Howlett BG, Inouye DW. Non-bee insects as visitors and pollinators of crops: Biology, ecology, and management. Annual Review of Entomology,2020:65(1):391–407.
65. Dar TA, Mir AH, Bharti M. Comparison of the sweeping net and bait method to access the species diversity of Calliphoridae (Insecta: Diptera) in Kashmir Himalaya, India. Journal of Asia-Pacific Biodiversity,2025:18(1):88–96.
66. Rangel J, Lau P, Strauss B, Hildinger E, Hernandez B, Rodriguez S, *et al*. Pollen associated with a Texas population of blow flies (Diptera: Calliphoridae) highlights underappreciated aspects of their biology. Ecological Entomology,2023:49(2):215–224.
67. Brown BV. Manual of Central American Diptera (Vol. 1). NRC Research Press; 2009.
68. Kutty SN, Pape T, Pont A, Wiegmann BM, Meier R. The Muscoidea (Diptera: Calyptratae) are paraphyletic: Evidence from four mitochondrial and four nuclear genes. Molecular Phylogenetics and Evolution,2008:49(2):639–652.
69. Bharti M. Current status of family Muscidae Diptera from India. Journal of Entomological Research,2008:32(2):171–176.
70. Mitra B. Diversity of flower visiting flies (Insecta: Diptera) in India and their role in pollination. Records of the Zoological Survey of India,2010:110(2):95–107.
71. Gallai N, Salles JM, Settele J, Vaissiere BE. Economic valuation of the vulnerability of world agriculture

confronted with pollinator decline. Ecological Economics,2009:68(3):810–821.
72. Potts SG, Fonseca VI, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, *et al*. The assessment report on pollinators, pollination and food production: Summary for policymakers. IPBES Secretariat; 2016.
73. Bashir MA, Saeed S, Sajjad A, Ali M. Seasonal variations in abundance and diversity of insect pollinators in forest ecosystems of Southern Punjab, Pakistan. Pure and Applied Biology,2015:4(3):441–452.
74. Ollerton J, Winfree R, Tarrant S. How many flowering plants are pollinated by animals. Oikos,2012:120(3):321–326.
75. Bartomeus I, Potts SG, Dewenter IS, Vaissiere BE, Woyciechowski M, Krewenka KM, *et al*. Contribution of insect pollinators to crop yield and quality varies with agricultural intensification. PeerJ,2014:2.
76. Calderone NW. Insect pollinated crops, insect pollinators and US agriculture: trend analysis of aggregate data for the period 1992–2009. PLoS One,2012:7(5):e37235.
77. FAO. Food and Agriculture Organisation of the United Nations. FAOSTAT Database, 2017.
78. Muhammad W, Ahmad M, Ahmad I. Pollination behaviour of cotton crop and its management. In Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies. Springer, Singapore,2020:163–175.
79. Khan F, Pervez M, Khan IA, Khan K, Hayat S, Bibi S, *et al*. Insect pollinators and their impact on maize yield in District Swat Khyber Pakhtunkhwa, Pakistan. Ricos Biology,2025:3(3):11–21.
80. Abrol DP, Shankar U. Role of pollination in pulses. Advances in Pollen Spore Research,2015:33:101–103.
81. Navatha L, Sreedevi K. Insect pollinator diversity and abundance in castor (*Ricinus communis* L.). Current Biotica,2012:6(3):351–355.
82. Ejaz K, Ali M, Khan FZA, Mozuratis R. Enhancing alfalfa (*Medicago sativa*) seed yield: The effect of honey bee (*Apis mellifera*) supplementation and efficiency of other pollinators. Biology,2025:14(6):599.
83. Islam R, Howlett BG, Chapman H, Haque MA, Ahmad M. The value of insect pollination to yield of oilseed rape (*Brassica rapa*) in Bangladesh. Journal of Asia-Pacific Entomology,2022:25(1):101844.
84. Rani B, Suresh K, Anand G, Shanthi M. Diversity of insect pollinators on sesame. Indian Journal of Entomology,2023:85(2).
85. Das R, Jha S. Insect pollinators of sesame and the effect of entomophilous pollination on seed production in New Alluvial Zone of West Bengal. International Journal of Current Microbiology and Applied Sciences,2019:8(3):1400–1409.
86. Padhy D, Satapathy CR, Borkataki S. Diversity of pollinators on sunflower. Indian Journal of Entomology,2024:86(1):98–104.
87. Sajjanar SM, Thippaiah M. Effect of different modes of pollination in sunflower (*Helianthus annuus* L.) hybrid seed production. Mysore Journal of Agricultural Sciences, 2021, 55(4).
88. Shultz KRH, Armstrong JS, Caballero M, Hoback WW, Knoll JE. Insect feeding on *Sorghum bicolor* pollen and Hymenoptera attraction to aphid-produced honeydew. Insects,2022:13(12):1152.
89. Siede R, Eickhoff B, Freyer C, Windpassinger S, Buchler R. The bioenergy crop *Sorghum bicolor* is a relevant pollen source for honey bees (*Apis mellifera*). GCB Bioenergy,2021:13(7):1149–1161.
90. McGregor SE. Insect pollination of cultivated crop plants. Agricultural Research Service, USDA, No. 496; 1976.
91. Elisante F, Ndakidemi P, Arnold SEJ, Belmain SR, Gurr GM, Darbyshire I, *et al*. Insect pollination is important in a smallholder bean farming system. PeerJ,2020:8.
92. Yogapriya A, Usharani B, Suresh K. Diversity and foraging activity of flower visitors/pollinators of *Momordica charantia* L. in Tamil Nadu, India. Entomon,2018:47(1):41–50.
93. Kaushik HD, Yadav S, Nadaf HA. Role of insect pollinators in tropical/sub-tropical/arid fruit crops. In Advances in Bio-ecology and Management of Insect Pollinators of Crops,2012:113.
94. Charan SK, Sharma P, Choudhary RD, Gunsaria S, Meena VK. Diversity of insect fauna actively engaged in pollination of *Vigna unguiculata* (L.) in Jaipur, Rajasthan, India. Uttar Pradesh Journal of Zoology,2023:44(14):42–51.
95. Mondal A, Abrol DP, Sharma P. Diversity of insects associated with eggplant flowers and their role in fruit production. Environment and Ecology,2022:40(4C):664–2668.
96. Balachandran C, Chandran MS, Vinay S, Shrikant N, Ranachandra TV. Pollinator diversity and foraging dynamics on monsoon crop of cucurbits in a traditional landscape of South Indian west coast. Biotropia,2017:24(1):16–27.
97. Ramirez VM, Tabla VP, Kevan PG, Morillo IR, Harries H, Barrera MF, *et al*. Mixed mating strategies and pollination by insects and wind in coconut palm (*Cocos nucifera* L.). Agricultural and Forest Entomology,2004:6(2):155–163.
98. Halder J, Karkute SG, Dasgupta J, Karmakar P, Singh AK, Chaubey T, *et al*. First record of *Epuraea motschulskyi* as a potential pollinator of pointed gourd (*Trichosanthes dioica* Roxb.): Biosystematics, molecular characterization, and pollination efficiency. Arthropod-Plant Interactions,2024:18(5):1099–1109.
99. Singh AK. Comparative performance of various pollinators in guava. Indian Journal of Horticulture,2020:77(1):206–209.
100. Kumari DA, Madhavi JM, Bhagwan A, Kumar MR. Surveillance of pollinators and their behaviour in mango flowers. Plant Archives,2014:14(2):727–729.
101. Umesh S. Insect pollinators of pumpkin (*Cucurbita pepo* L.) and their foraging behaviour. Doctoral Dissertation, MPUAT Udaipur, 2020.
102. Longkumer B, Devi HS, Chauhan A, Neog P, Singh MS. Studies on impact of different pollinators in pumpkin (*Cucurbita moschata* Duch. ex Poir). The Pharma Innovation Journal,2024:13(12):170–174.
103. Thakur M, Rana RS. Studies on the role of insect pollination on cucumber yield. Pest Technology,2008:2(2):130–133.
104. Hanif R, Yaqoob M, Ayoub L, Salma S, Siraj M, Wani FF, *et al*. Role of insect pollinators in pollination of cucumber. The Pharma Innovation Journal,2022:11(4):737–742.

105. Singh J, Kumar NR, Devi A. Insect pollinators, their diversity, foraging behaviour and relative abundance on litchi, okra and sarson. Entomon,2017:42(4):275–282.
106. Subbanna ARNS, Paschapur AU, Bhat S, Chaudhari G, Dev R, Hedau NK, *et al*. Effect of insect pollinators on quantitative yield parameters of okra (*Abelmoschus esculentus*) in mid-Himalayan region. Indian Journal of Agricultural Sciences,2024:94(12):1349–1353.
107. Deeksha MG, Khan MS, Kumaranag KM. Plant-pollinator interaction network among the scrubland weed flora from foothills of north-western Indian Himalaya. International Journal of Tropical Insect Science,2022:42(2):1593–1603.
108. Benvenuti S. Weed role for pollinator in the agroecosystem: Plant–insect interactions and agronomic strategies for biodiversity conservation. Plants,2024:13(16):2249.
109. Kleiman BM, Koptur S, Jayachandran K. Weeds enhance pollinator diversity and fruit yield in mango. Insects,2021:12(12):1114.
110. Shrestha M, Dyer AG, Gerny SB, Wong BB, Burd M. Shades of red: Bird-pollinated flowers target the specific colour discrimination abilities of avian vision. New Phytologist,2013:198(1):301–310.
111. Tekulsky M. How to create a butterfly garden: Bringing the beauty of butterflies into your world. Simon and Schuster, New York; 2023.
112. Vaudo AD, Tooker JF, Patch HM, Biddinger DJ, Coccia M, Crone MK, *et al*. Pollen protein: Lipid macronutrient ratios may guide broad patterns of bee species floral preferences. Insects,2020:11(2):132.
113. Borghi M, Fernie AR. Floral metabolism of sugars and amino acids: Implications for pollinators' preferences and seed and fruit set. Plant Physiology,2017:175(4):1510–1524.
114. Reverte S, Retana J, Gomez JM, Bosch J. Pollinators show flower colour preferences but flowers with similar colours do not attract similar pollinators. Annals of Botany,2016:118(2):249–257.
115. Wang H, Ran N, Jiang HQ, Wang QQ, Ye M, Bowler PA, *et al*. Complex floral traits shape pollinator attraction to flowering plants in urban greenspaces. Urban Forestry & Urban Greening, 2024, 91.
116. Weber UK, Nuismer SL, Espinodola A. Patterns of floral morphology in relation to climate and floral visitors. Annals of Botany,2020:125(3):433–445.
117. USDA Forest Service. Pollinator syndromes. Celebrating Wildflowers Journal, USDA Forest Service, 2026.
118. KC U, Sharma S, Subba A, Pandey N, Singh AK, Koju NP, *et al*. Floral preferences of butterflies based on plant traits: A case study in the National Botanical Garden, Godawari, Nepal. Journal of Zoological and Botanical Gardens,2025:6(2):30.
119. Garcia JE, Hannah L, Shrestha M, Burd M, Dyer AG. Fly pollination drives convergence of flower coloration. New Phytologist,2022:233:52–61.
120. USDA Forest Service. Beetle pollination. Celebrating Wildflowers Journal, USDA Forest Service, 2026.
121. Karbassioon A, Yearlsey J, Dirilgen T, Hodge S, Stout JC, Stanley DA. Responses in honeybee and bumblebee activity to changes in weather conditions. Oecologia,2023:201(3):689–701.
122. Ansari A, Memon N, Shah MA, Amur A, Mal B. Seasonal variation and diversity of hoverflies fauna (Diptera: Syrphidae) in central Sindh, Pakistan. Sarhad Journal of Agriculture,2017:33(4):653–660.
123. Gautam PP, Kumar N. Pollinator diversity and relative abundance of insect pollinators on ridge gourd (*Luffa acutangula*) flowers in Bihar, India. Journal of Entomology and Zoology Studies,2018:6(2):1177–1181.
124. Lawson DA, Rands SA. The effects of rainfall on plant–pollinator interactions. Arthropod-Plant Interactions,2019:13(4):561–569.
125. Turshak LG, Emmanuel P, Ibrahim JI, Chaskda AA, Mwansat GS. Vegetation and weather as drivers of butterfly species richness and abundance in a conservatory, Central Nigeria. Journal of Research in Forestry, Wildlife and Environment,2023:15(4):209–215.
126. Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R, *et al*. A global synthesis reveals biodiversity-mediated benefits for crop production. Science Advances, 2019, 5(10).
127. Nath R, Singh H, Mukherjee S. Insect pollinators decline: An emerging concern of Anthropocene epoch. Journal of Apicultural Research,2023:62(1):23–38.
128. Brunet J, Fragoso FP. What are the main reasons for the worldwide decline in pollinator populations? CABI Reviews, 2024, 19(1).