# From Pollinators to Pests: The Dual Roles of Insects in Shaping Agricultural Landscapes


## Abstract

Insects play a pivotal role in agriculture, acting both as beneficial pollinators and as destructive pests. Pollinators, such as bees, butterflies, and other insects, are essential for the successful reproduction of many crops, enhancing biodiversity and contributing significantly to global food production. Conversely, insect pests pose substantial threats to agricultural productivity by damaging crops, leading to economic losses and increased reliance on chemical pesticides. This duality underscores the complex interplay between insects and agricultural systems, necessitating integrated pest management strategies that balance the promotion of pollinators and the control of pests. Understanding and managing these dual roles are crucial for sustainable agricultural practices, ensuring food security while maintaining ecological balance.


Keywords: bees, biodiversity, roles, chemical, productivity, complex




## Introduction

It is still a worldwide problem to fulfil the nutritional needs of the future in a sustainable manner while staying within the constraints of our planet. 75% of the world's most important crops, which account for an estimated 35% of the world's food output, benefit from increased yield and quality when they are pollinated by insects[1]. These insect-pollinated crops include legumes, nuts, and fruits, all of which are exceptionally abundant in proteins, lipids, and micronutrients that are essential to human health. The preservation of healthy pollinator assemblages is absolutely necessary in order to accomplish our goal of meeting future nutritional demands in a sustainable manner[2]. Researchers have shown that one of the key factors contributing to the loss of insect pollinators is the increase of farming techniques. Through agri-environmental legislation and the marketing of goods that are favourable to the environment, agriculture has the potential to become an important vehicle for the conservation of pollinators[3]. Due to the fact that nearly forty percent of the European Union is comprised of agricultural output, it is difficult to comprehend how we can effectively protect pollinators without taking into consideration the agricultural matrix[4].

With plant-based proteins serving as an alternative to proteins produced from meat, dietary adjustments toward more plant-based diets have a significant part to play in the process of achieving food security[5]. Not only can grain legumes, which include beans, peas, and soybean, offer a substantial amount of protein for human consumption, but they also serve as a source of feed for cattle, therefore lowering the need for soybeans that are imported into European nations. Since of their ability to fix nitrogen from the atmosphere, legumes are particularly beneficial since they reduce the amount of inorganic nitrogen that an organism needs[6].

There is a significant dependency between pollinators and legumes, with legumes being an important source of fodder while also being dependent on insect pollination for sexual reproduction and the preservation of genetic variety[7]. These interdependencies are reliant on the characteristics of both the plant (such as the flowering season, the quality and amount of nectar and pollen, and the form of the flower, which will impact accessibility) and the pollinator (such as the length of the tongue, the activity period, and the nutritional requirements)[8]. However, the value of legumes to pollinators has been called into question due to the fact that grain monocultures have a limited flowering period, the frequency of grazing and cutting in forage legumes limits flowering, and the complex flower structures of legumes restrict the accessibility of resources to pollinating taxa that have short mouthparts[9]. It is necessary to identify multifunctional legume cropping systems in order to inform policy. These systems should be able to offer a stable and easily available feed for a wide variety of wild pollinators, while still preserving a wide range of agronomic and environmental advantages[10]. Plant-pollinator interactions are essential to the production of agricultural food and contribute to the preservation of biodiversity on a global scale. It is estimated that around 87.5% of flowering plants are dependent on animal pollinators for reproduction. Furthermore, animal pollination is responsible for the reproduction of 87 of the main food crops worldwide and 35% of the total output volumes worldwide. On the other hand, the number of pollinators that are disappearing from various regions of the planet may present an important ecological concern[11].

Pollinators are groupings of animals that are quite varied and are responsible for the transmission of pollen from flowering plants to other plants. There have been over 140,000 different species of insects reported, making them the most varied and numerous pollinators. Diptera and Thysanoptera, which are often believed to be pests, have been mostly overlooked while their involvement in pollination has been completely ignored[12]. These two groups have the least diversity. There is evidence that hoverflies belonging to the groups Syrphinae and Eristalinae are responsible for pollination. There is a lack of documentation on the pollinators that are found in moths and flies; nevertheless, it is anticipated that future study may find additional pollinators within these and other invertebrate species[13].

There is evidence that birds are the most diversified group of vertebrates, with over one thousand species being documented as pollinators. Vertebrates can also be excellent pollinators. In addition, bats play a significant role in the pollination of crops and wild plants. Pteropodid and phyllostomid bats are responsible for pollinating about 528 species of flowering plants belonging to 259 genera[14]. When it comes to pollination, other animal species such as reptiles, rodents, lemurs, and marsupials are important contributors; nonetheless, they receive very little attention. There is a lack of research on reptile pollination, despite the fact that nectar-drinking lizards have been observed in recent times[15].

Researchers appear to concentrate their efforts mostly on bees, while sociological studies have shown that the great majority of farmers throughout the world have a poor grasp of the impact that pollinator variety makes to crop productivity[16]. For agricultural pollination, honeybees are the sole source of reliance for the majority of large-scale farmers in Europe. As a result of the limited amount of study that has been conducted on the subject of the contributions of non-bee pollinators to crop productivity, there is not yet a consensus about the role that pollinator diversity plays in agricultural ecosystems[17].

**Importance of pollinator for agriculture**

When it comes to blooming plants, the diversity of pollinators is an extremely important factor in seed production and recruitment. Several studies have demonstrated that the presence of a positive correlation between reproductive success in natural plant communities and the functional variety of pollinators[18]. It has been demonstrated that plants that are visited by a community of pollinators that are functionally varied do yield seeds of a high quality and quantity. However, there has not been a lot of research done on the impact that different floral visitors have in seedling recruitment[19]. Fontaine et al. (2006) conducted an experiment in which they manipulated the functional diversity of both plants and pollinators. They discovered that an increase in the variety of functional pollinators led to an increase in the number of plant species that were present in a plant community[20]. In a similar vein, Lundgren et al. (2015) observed a decrease in seedling recruitment in terms of plant species richness after they prevented some pollinators from visiting flowers for a period of four years. Because of this, the diversity of pollinators has the potential to increase the longevity of plant communities by encouraging the generation of seeds and the recruitment of seedlings[20]. It is possible that the post-seed production period is where the influence of pollinator variety in plant communities will become apparent. Investigations that are conducted over an extended period of time are required in order to shed light on such linkages[21].

It is possible that a lack of pollen might have an effect on the functioning of the ecosystem, as well as on the distribution and abundance of plant species. A meta-analysis that was conducted not too long ago revealed that in the Anthropocene, plants that are ecologically and functionally specialized are at danger of experiencing pollen restriction[22]. In this ever-evolving planet, it may be of the utmost importance to preserve the diversity of pollinators, as the loss of pollinators may result in the extinction of plants that are dependent on pollinators. There has been a correlation established between pollen restriction and low pollinator species richness within plant ecosystems[23]. Pollen limitation may also be prevented by diverse pollinator assemblages because to variations in foraging distances and flower-visiting behaviours that are particular to individual pollinators. Pollinator behaviour is influenced by competition for floral resources among taxonomically varied pollinators, which may lead to an increase in the total pollination rate[24].

Pollinator variety has the potential to promote pollination in natural plant communities during times of environmental disturbance, which might help overcome the problem of pollen restriction. In some cases, the quality of agricultural produce can be determined by the diversity of pollinators[25]. Research has not yet been conducted to investigate the methods by which the abundance of pollinator species affects the productivity and quality of agricultural products. Pollinators that are functionally diverse, on the other hand, have the potential to promote gene flow and increase genetic variety. There have been studies that have demonstrated that crop yields that are cross-pollinated are of a greater quality than those that are self-pollinated[26]. These cross-pollinated crops are subjected to a higher level of pollinator complementarity, which reduces the adverse impacts of a number of parameters on the effectiveness of pollination. These factors include environmental and climatic conditions, the distance between the nest and the feed, and the time of day or night. Therefore, pollinators in a wide range of taxonomic categories might be a potential solution to the problem of sustaining good crop quality in the face of climate change[27].

One of the most important factors in increasing agricultural productivity is the diversity of pollinators, which is responsible for determining the fruit set of a wide variety of crops, including coffee, almonds, pumpkin, and apples. The quantity of yield in oilseed rape, which is a crop that is essential on a worldwide scale, has been proven to rise when there is a high functional pollinator diversity, according to studies[28]. Regardless of the density of managed honeybees, it has been demonstrated that the diversity of wild bees is the most important factor in determining fruit set in apple crop orchards located in rural areas. The rise in the number of wild pollinators is a crucial factor that contributes to the production of fruit in ecosystems that have a high flower visitation rate by honeybees. Furthermore, it is worth noting that the seed set of the jalapeño crop is greatly augmented when urban settings exhibit a high pollinator species diversity[29].

It is possible that a high amount of crop output in agricultural systems that have a high floral visitor richness is connected with the pollinator complementarity that is given by taxonomically diverse pollinators. For instance, honeybees have a greater preference for floral density in apple orchards, but wild bees have a lower preference for floral density. In the cotton agricultural environment of the Gulf Coast of the United States, non-bee pollinators, notably flies and butterflies, give an equivalent functional visitation space to bee pollinators[30]. When it came to establishing inter-annual stability in agricultural pollinator groups across the world, pollinator temporal complementarity was very necessary. The spatial and temporal complementarity among various pollinator guilds leads to a rise in the proportion of flowers pollinated during crop blooming times, which in turn leads to an increase in the quantity of agricultural produce[31].

By acting as ecological indicators, a wide variety of pollinators make a contribution to the protection of the environment and the health of humans. As a result of their great sensitivity to manmade pollution, insect pollinators like bees and butterflies have proven to be effective in monitoring the changes that occur in the environment[32]. There is evidence that nymphalid butterflies, also known as *Danaus chrysippus*, might serve as an indication of heavy metal contamination caused by cadmium and copper. As a result of their ability to detect seasonal variations in copper, zinc, manganese, and iron in urban environments, honeybees (Apis) have been proven to be helpful in ecological monitoring[33]. Environmentalists may utilize honeybees to monitor these elements. Bats have the potential to act as bio-indicators due to the fact that they are directly connected to the environment, they fly across a large geographical area in search of insects, pollen, and nectar, and they store chemical compounds that may provide crucial ecological information[34].

Biological control is an efficient approach for controlling disease-vector populations, particularly in situations where the rates of predation are high and sufficient to prevent the introduction of infections in populations of beneficial animals or plants. Recent research has demonstrated that bats devour a greater quantity of dipterans, which are responsible for the transmission of the greatest number of disease-causing organisms, such as mosquitoes, than in the past[35]. The use of pollinators to manage crop diseases is now feasible because to the development of modern technology. One example of this is the employment of *Bombus terrestris*, which has been successfully employed to restrict the spread of microorganisms on strawberries grown in a greenhouse. Pollinators that manage pests and disease vectors may be conserved, which would result in a significant reduction in the usage of pesticides, which would be beneficial to both the environment and human health[36].

**<u>Word wide strategies adopted by pollinators</u>**

Plants have created their own unique techniques for attracting pollinators, such as mimicry and entrapration. Mimicry is the process by which plants use their aroma or form to attract pollinators. For example, flowers that resemble decaying meat attract flies for the purpose of obtaining food or eggs[37]. In order to guarantee that pollination occurs, entrapment employs a mixture of these tactics, which involves capturing the pollinator within the bloom. It is possible to do this by the formation of fluid pools, the closure of flowers, or the movement of one flower part in reaction to the presence of a pollinator on another flower part[38].

In addition to being one of the oldest pollinators, beetles are responsible for pollinating some of the earliest angiosperms, which dates back more than 120 million years. The Magnolia, the Asimina (paw-paw), the Sassafras, and the Calycanthus (sweetshrub) are examples of common temperate ornamental plants that are pollinated by beetles. It is possible for beetles to be drawn to a variety of doors, and they are able to consume petals and other components of flowers in order to get nectar. Because they have such a huge variety of species, they are an essential pollinator all throughout the world[39].

Flies are another category of pollinators that are not as widely known, and they may even be the first. In the process of expanding floral diversity during the course of evolution, pollination by flies is second only to pollination by bees[40]. Generally speaking, flies are drawn to flowers that have a terrible odour and are pale, drab purple to brown in colour. Flowers frequently funnel or trap the insects within in order to guarantee that pollination occurs. *Arisaema triphyllum*, Asimina (paw-paw), and *Trillium erectum* are examples of common flowers that have the ability to attract flies and insects for the purpose of pollination through the use of offensive odours[41].

There are also other pollinators that are not as frequent, such as wasps, ants, moths, birds, and bats. In the south western region of the United States, bats are also a popular pollinator for a variety of cactus species. Generally speaking, plants have created their own distinct tactics in order to ensure pollination and to keep their health intact[42].

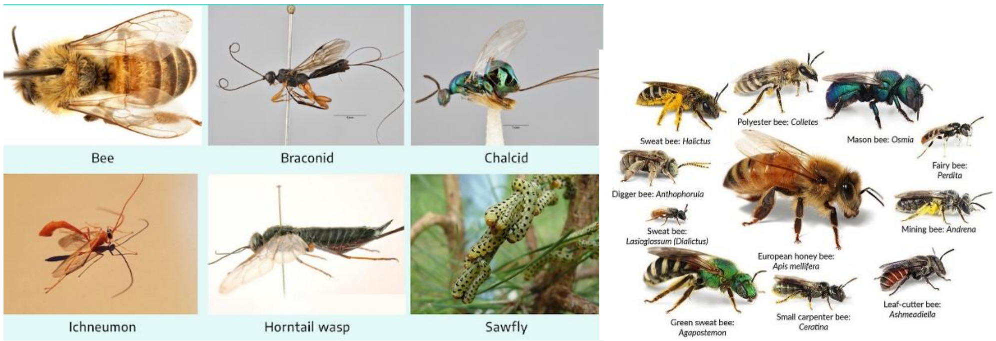


**Fig 1. Different types of flies and bees**

**Economical effect**

As a result of difficulties such as climate change, changes in land use, habitat modification, and the expansion of the human population, there is an increasing demand for food security. Pollination done correctly has the potential to increase both the number and quality of crops that are produced, with animal pollination giving an extra contribution of USD 235-577 billion yearly. Although this results in an increase in the need for pollination services, it is important to note that without animal pollination, between 5 and 8 percent of agricultural yield would be lost[43].

It is estimated that bees are responsible for 9.5% of the overall economic value of agricultural products that is utilized directly for human nourishment. Bees are the primary pollinators of plants. There is a larger dependence on pollination in agriculture on a broad scale in nations that cultivate cash crops such as coffee, cocoa, almonds, and soybeans[44]. In the United States of America, it has been demonstrated that the yearly benefit of some ecological expenses suffered by native insects amounts to more than 57 billion dollars, with honey bees providing roughly 11.68 billion dollars by the year 2009. Honey bees are vital for pollinating more than one hundred commercial crops in North America. Sunflower seed production is an economically significant industry that relies heavily on honey bees[45].

There is also an increase in the yield of crops that are grown on farms, such as cotton in sub-Saharan Africa and smallholder farming methods in Kakamega (western Kenya). Bee pollination is responsible for this growth. Over the course of 2016, the yearly value of pollination services provided by bees in Brazil's protected areas was estimated to be roughly USD 564,000 in the northern region (Serra da Bocaina, Pará) and USD 246,000 in the southern region (Mata do Jambreiro)[46]. Honey bees and wild bees have been shown to deliver equivalent amounts of pollination for the majority of crops in the United States of America, especially in regions that are highly agriculturally intensive. The yearly production value of wild pollinators for seven different crops in the United States is about one and a half billion dollars, with apples having the highest value. The impact that honey bees have on the output of these crops is estimated to be worth around 6.4 billion US dollars[47].

**Types of bees and their roles in pollination**

The frequency of visits and the cumulative impacts of different species of bees have an impact not only on the quantity of crops that are produced but also on the quality of those crops, which is significant primarily regarding the economic aspect of the situation. A more effective pollination and vegetative process is achieved when many species of bees, such as honey bees, carpenter bees, stingless bees, bumble bees, long-tongued bees, feral bees, social bees, and solitary bees, work together to pollinate a plant[48].

Since the beginning of the practice of providing pollination services, Western honey bees have been utilized extensively as pollinators. They are the principal species that are handled from a global perspective for the purpose of honey production as well as crop pollination. In the United States of

America, honey bees were projected to have contributed 11.68 billion dollars to the agricultural sector in 2009[49]. It is well acknowledged that honey bees are among the most important pollinators owing to their efficiency and widespread availability. The exchange of nectar and pollen between honey bees and plants is the source of the mutualistic relationship that exists between the two of them. When plants produce a rich liquid sugar that is comparable to nectar, they release it from their glands in order to attract pollinators to their blossoms[50]. This allows the pollen to stick to the pollen grains that have been gathered by bees. Bees play an essential part in the process of pollination. It has been discovered by researchers that honey bees (*A. mellifera L.*) tend to choose crops that are abundant in nectar and pollen. This is because honey bees are able to store huge quantities of food, which leads to the maintenance of colony expansion and an improvement in foraging performance[51].

Many nations have made use of honey bees and have seen significant improvements in both the quality and quantity of their agricultural output as a result. In the United States of America, honey bees are well acknowledged for their ability to pollinate three different types of crops: cucumbers (*Cucumis sativus Linn*), cranberries (*Vaccinium oxycoccos Linn*), and pears (*Pyrus communis Linn*)[52]. In India, the utilization of honey bees as pollinators resulted in an improvement in the quality of the fruit of guava (*Psidium guajava Linn*), as well as an increase in the length and girth of the fruit of coconut (*Cocos nucifera Linn*) and citrus (*Citrus spp.*). The proportion of seeds that are set and the amount of seeds that are produced by onion (*Allium cepa Linn*) crops in Egypt have both been greatly enhanced by honey bees in comparison to other insects[53].

A large amount of the output of anise is also dependent on the activity of pollinators. Honey bees demonstrated a daily peak in anise pollination activity between the hours of noon and two o'clock in the afternoon[54]. They also showed a gain in yield that was greater than what was observed with insect exclusion, despite the fact that the levels were lower than those achieved with open pollination. Honey bees and six different species of Andrenidae are the primary pollinators of coriander. Honey bees are responsible for 63% of the visits, while three different species of Andrenidae are responsible for 100% of the visits[55].

As a result of their role as critical pollinators for agricultural and wild plants all over the world, bumble bees contribute to the safety of food supplies. There are five species of bumble bees that are frequently used for commercial crop pollination. These include Bombus terrestris Linn, which is used in Europe, North Africa, Asia, and Australasia; B. occidentalis Greene, which is used in western North America; B. ignitus and B. lucorum Linn, which are used in East Asia; and B. impatiens Cressant, which is used in North America. It is possible for them to continue foraging even when temperatures are extremely hot or extremely low because of their excellent adaption to a variety of climates and environments[56].

For example, kiwifruit, sweet pepper, and red clover have all benefited from the presence of bumble bees, which have been responsible for raising crop yields and improving the overall quality of these products. In addition to being significant pollinators for a wide variety of crops, they are also key pollinators for buzz-pollinated crops such as blueberry and tomato, as well as crops with big flowers and crops with small flowers[57]. In India, the buzz pollination process carried out by *Bombus haemorrhoidalis* Smith results in fruits that are larger, longer, heavier, and healthier, particularly in the case of kiwi fruit[58].

Pollination by bumble bees improves the quality and quantity of tomato fruit. This includes the number of fruits that are produced by each cluster, the number of fruits that are produced by each plant, the length of the fruit, the freshness of the fruit, the width of the fruit, and the yield of the fruit. Bumble bees are responsible for the pollination of sweet peppers, which results in a greater quantity of pollen grains and a greater number of seeds being put on the fruit than the process of self-pollination[59].

Stingless bees are extremely regular visitors to flower arrangements in tropical and subtropical regions all over the world. They have a broader variety of diets and a more intense foraging activity than honey bees, and they are expected to have an impact on the development of pollination solutions in the future that are tailored to work best with certain crops and environments. There is a vast and diversified set of eusocial bees that are appropriate for flower pollination[60]. This is because their structures are suitable for gathering pollen and nectar, and they do not engage in any activity that might be considered stinging. Certain species of stingless bees, such as those belonging to the genus Melipona, are capable of extracting pollen by vibrational activity. This is necessary for crops that have anthers that are capable of killing pests, such as tomato and pepper[61].

As a conclusion, it can be stated that bumble bees, stingless bees, and stingless bees all play significant roles in the process of pollinating a wide variety of crops and environments. Their capacity for adaptation and their capacity to continue foraging even in temperatures that are both high and low contribute to the crucial role that they play in crop pollination and in ensuring food security[62].

It is well known that the Carpenter bees, which are a kind of bees that are prevalent in tropical and subtropical regions, are capable of pollinating a wide variety of plants. When they are active for extended periods of time, they consume a broad variety of plant species. Additionally, they have the ability to buzz-pollinate flowers, which makes them more varied crop pollinators. On the other hand, there is a requirement for an adequate breeding program that incorporates the selection of genotypes, regulated mating, and the establishment of nest foundations[63].

It is possible for carpenter bees to construct their nests in tunnels that are buried in hard wood, logs, stumps, or dead plant branches. In India, they are productive throughout the whole year, foraging on a wide variety of flowers throughout the day and occasionally working through the night, when the moon is not visible[64]. There is a possibility that the smell of flowers that carpenter bees visit might act as a signal to visit the appropriate blooms.

It has been noted in the Philippines, Brazil, the United States of America, and Malaysia that the utilization of carpenter bees for the purpose of providing pollination services is essential for a number of crops, including passion fruit, cucurbits, vegetables, and fruits. When the blossoms of yellow passion fruit are solely visited by native bees, particularly carpenter bees, the fruit is pollinated and produced to a satisfactory level[65].

Solitary bees, which make up 85 percent of all bee species, are responsible for a significant portion of the pollination process. The pollination services provided by wild bees are valued at USD 3251 per hectare across the globe, with seven out of ten of these bees being solitary. There are certain crops, such as apple production, that are dependent on pollinators for their reproduction[66]. Honey bees are not as successful as solitary bees when it comes to pollinating certain of these crops. According to estimates, the economic benefits of utilizing solitary bees for apple production in the United Kingdom are expected to be 51.4 million euros, while the benefits of using honey bees are predicted to be 21.4 million euros[67].

**<u>Pollinators for seed production</u>**

A significant proportion of blooming plants have developed mechanisms that allow them to be pollinated by animals. The remaining flowering plants are either pollinated by the wind or are entirely dependent on their own seed generation[68]. The degree to which plants are ecologically dependent on certain pollen-vectors for the development of seeds is determined by the breeding systems that they use. Plants that are dioecious or genetically self-incompatible are completely reliant on cross-pollination for the development of seeds. Approximately fifty percent of angiosperms are classified as being in this group[69]. As a result of the geographical or temporal separation of their reproductive organs, self-compatible plants sometimes have an obligatory dependency on pollen carriers. The majority of plants that are self-compatible engage in mixed mating and lie somewhere along a continuum that extends from selfing to outcrossing[70].

It is estimated that around half of all plant species require cross-pollination in order to produce seeds.

This process contributes to increased seed production and improved performance of offspring in a great number of self-compatible species. This is due to the fact that cross-fertilization lessens the chance of inbreeding depression and encourages the accumulation of genetic variety, which in turn enables plant species to adapt to new and shifting environments[71]. Studies that involved the supplementary hand-pollination of flowers have demonstrated that the amount and quality of pollen that plants receive naturally is frequently the limiting factor in the amount of seeds that they produce. This phenomena takes place naturally in environments that are generally undisturbed, but it is made worse when plant populations become tiny and fragmented. Plants that are not compatible with themselves are more likely to encounter pollen restriction than plants that are compatible with themselves[72].

**Fig 2. Pollination**

It should come as no surprise that the presence of efficient pollinators within plant communities is a necessary condition for the successful generation of seeds in the majority of plant species. It is possible for plants to fail to produce fruits or seeds if they are selectively excluded from a certain group of pollinators that are successful. After conducting a worldwide meta-analysis, researchers found that excluding vertebrate pollinators from blooming plants that they visited resulted in a loss of fruit or seed production that was, on average, 63% lower[73].

Table 1. Table summarizing various fruits, their primary pollinators, and the role these pollinators play in the pollination process:

| **Fruit** | **Primary Pollinators** | **Role in Pollination** |
|---|---|---|
| Apples | Bees (honeybees, bumblebees) | Bees transfer pollen from the male parts (anthers) of one flower to the female parts (stigma) of another, facilitating cross-pollination. [74] |
| Blueberries | Bees (honeybees, bumblebees) | Bees vibrate flowers to release pollen, improving fruit set and quality. |
| Cherries | Bees (honeybees, mason bees) | Bees cross-pollinate flowers, which is essential for fruit set in most cherry varieties. [75] |
| Citrus Fruits | Bees (honeybees) | Bees pollinate flowers, increasing fruit set and quality, though some citrus can self-pollinate. |
| Strawberries | Bees (honeybees, bumblebees) | Bees enhance pollination, leading to larger and more evenly shaped fruits. [76] |

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|---|---|---|
| Watermelons | Bees (honeybees, squash bees) | Bees pollinate female flowers, which require pollen from male flowers to develop fruit. [77] |
| Almonds | Honeybees | Almonds are entirely dependent on honeybee pollination for nut production. [78] |
| Peaches | Bees (honeybees, bumblebees) | Bees improve fruit set and quality, though peaches are somewhat self-fertile. [79] |
| Tomatoes | Bumblebees, solitary bees | Bees, particularly bumblebees, use buzz pollination to release pollen from flowers, aiding in fruit development. |
| Pumpkins | Squash bees, honeybees | Bees transfer pollen from male to female flowers, essential for fruit development. [80] |
| Raspberries | Bees (honeybees, bumblebees) | Bees pollinate flowers, enhancing fruit size, yield, and quality. [81] |
| Grapes | Wind, insects (varies) | Most grape varieties are self-pollinating, but insect activity can aid in pollen transfer. [82] |
| Mangoes | Flies, bees | Insects, particularly flies and bees, help in cross-pollination, improving fruit set and quality. [83] |
| Avocados | Bees, flies | Insect pollinators, mainly bees, enhance the transfer of pollen from male to female flowers, crucial for fruit set. [84] |
| Cantaloupes | Bees (honeybees, squash bees) | Bees are essential for transferring pollen from male to female flowers, necessary for fruit development. |
| Blackberries | Bees (honeybees, bumblebees) | Bees aid in the cross-pollination of flowers, improving fruit set and yield. [85] |

Table 2. Agronomical crops, their primary pollinators, and the role these pollinators play in the pollination process:

| **Agronomical Crop** | **Primary Pollinators** | **Role in Pollination** |
|---|---|---|
| Alfalfa | Bees (leafcutter bees) | Bees trip the flowers to release pollen, essential for seed production and improving forage yield. [86] |
| Canola | Bees (honeybees, bumblebees) | Bees transfer pollen between flowers, increasing seed set and oil content. [87] |
| Cotton | Bees (honeybees, bumblebees) | Bees enhance pollination, leading to higher yields and improved fibre quality. [88] |
| Soybeans | Bees (honeybees) | Bees increase pod set and seed yield, although soybeans are primarily self-pollinating. |
| Sunflowers | Bees (honeybees, bumblebees) | Bees pollinate flowers, increasing seed set, yield, and oil content. [89] |
| Coffee | Bees (various species) | Bees improve fruit set and quality, as coffee plants benefit from cross-pollination. |
| Buckwheat | Bees (honeybees, solitary bees) | Bees enhance cross-pollination, leading to better seed set and yield. [90] |
| Clovers (Red, White) | Bees (honeybees, bumblebees) | Bees pollinate flowers, essential for seed production and improving forage quality. [91] |
| Carrots (seed crop) | Bees (honeybees) | Bees transfer pollen between umbels, critical for hybrid seed production. [92] |
| Squash and Pumpkins | Bees (squash bees, honeybees) | Bees transfer pollen from male to female flowers, necessary for fruit development. |

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|---|---|---|
| Cucumbers | Bees (honeybees, bumblebees) | Bees pollinate female flowers, crucial for fruit set and development. [93] |
| Mustard | Bees (honeybees, bumblebees) | Bees increase pollination efficiency, leading to higher seed yield and oil content. |
| Sesame | Bees (honeybees, solitary bees) | Bees enhance cross-pollination, improving seed set and oil quality. [94] |
| Tomatoes (greenhouse) | Bumblebees | Bumblebees perform buzz pollination, essential for fruit set in greenhouse environments. |
| Peppers | Bees (honeybees, bumblebees) | Bees enhance pollination, leading to better fruit set and quality. [95] |
| Eggplants | Bees (solitary bees, bumblebees) | Bees facilitate cross-pollination, improving fruit set and size. |
| Almonds | Honeybees | Almonds depend entirely on honeybee pollination for nut production. [96] |
| Lentils | Bees (honeybees) | Bees increase seed yield through effective pollination, though lentils are primarily self-pollinating. [97] |
| Oilseed Rape | Bees (honeybees, bumblebees) | Bees enhance seed set and oil content through effective pollination. [98] |

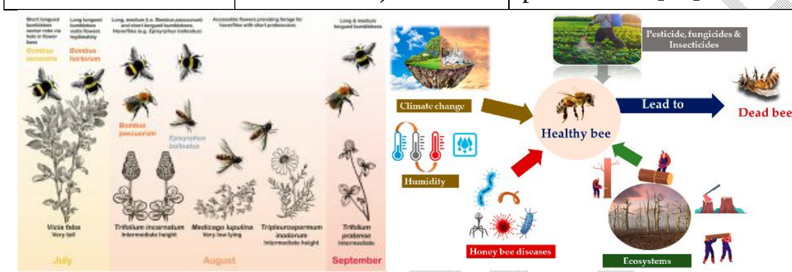


Fig 3. Factors influencing pollination

Table 3. Vegetable crops, their primary pollinators, and the role these pollinators play in the pollination process:

| **Vegetable Crop** | **Primary Pollinators** | **Role in Pollination** |
|---|---|---|
| Tomatoes | Bumblebees | Bumblebees perform buzz pollination, essential for effective fruit set. [99] |
| Cucumbers | Bees (honeybees, bumblebees) | Bees transfer pollen from male to female flowers, crucial for fruit development. [100] |
| Zucchini | Bees (honeybees, squash bees) | Bees pollinate female flowers, necessary for fruit set. |
| Pumpkins | Bees (honeybees, squash bees) | Bees transfer pollen from male to female flowers, essential for fruit development. [101] |
| Squash | Bees (honeybees, squash bees) | Bees pollinate female flowers, which is crucial for fruit development. [102] |
| Peppers | Bees (honeybees, bumblebees) | Bees enhance pollination, leading to better fruit set and quality. [103] |
| Eggplants | Bees (solitary bees, bumblebees) | Bees facilitate cross-pollination, improving fruit set and size. |
| Carrots (seed crop) | Bees (honeybees) | Bees transfer pollen between umbels, critical for hybrid seed production. [104] |

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| Onions (seed crop) | Bees (honeybees) | Bees transfer pollen, essential for seed production. |
| Broccoli (seed crop) | Bees (honeybees, bumblebees) | Bees pollinate flowers, crucial for seed set and production. [105] |
| Cauliflower (seed crop) | Bees (honeybees, bumblebees) | Bees are necessary for effective cross-pollination, leading to seed set. [106] |
| Lettuce (seed crop) | Bees (honeybees) | Bees enhance cross-pollination, leading to better seed yield. [107] |
| Radishes (seed crop) | Bees (honeybees, solitary bees) | Bees improve seed set through effective pollination. |
| Melons | Bees (honeybees, bumblebees) | Bees are essential for transferring pollen from male to female flowers, necessary for fruit development. [108] |
| Watermelons | Bees (honeybees, squash bees) | Bees pollinate female flowers, essential for fruit set. |
| Beans | Bees (honeybees, bumblebees) | Bees enhance pollination, which can improve pod set and yield, although beans can also self-pollinate. [109] |
| Peas | Bees (honeybees) | Bees increase pollination efficiency, leading to higher yield, although peas are primarily self-pollinating. [110] |
| Okra | Bees (honeybees, bumblebees) | Bees transfer pollen between flowers, improving fruit set and yield. [111] |
| Celery (seed crop) | Bees (honeybees) | Bees are necessary for effective pollination, leading to seed production. [112] |
| Spinach (seed crop) | Bees (honeybees) | Bees enhance cross-pollination, crucial for seed set and yield. [113] |



**Conclusion**

Insects' pollinating and pestilential roles shape agricultural environments. comprehending agricultural ecosystems and their fragile balance requires comprehending this process. Through their various interactions with plants, insects affect crop yield, biodiversity, and agricultural sustainability. This conclusion will consolidate insects' various roles in agriculture, emphasize their benefits and problems, and recommend integrated measures to maximize their benefits and minimize their drawbacks. Farmers need insects as pollinators to reproduce many crops. About 75% of the world's food crops are pollinated by bees, butterflies, and flies. These pollinators improve fruit set, quality, and yield in fruits, vegetables, and nuts. Apples, almonds, and blueberries require bees for pollination. Insect pollinators produce billions of dollars in ecological services, highlighting their economic value. Pollinators help plants reproduce sexually, which increases genetic variety and resistance to environmental changes and diseases. However, habitat loss, pesticide usage, climate change, and illnesses are threatening pollinators' positive function. Reduced pollinator numbers threaten global food security and biodiversity. Pollinators lose feeding and breeding grounds due to urbanization and agricultural growth. Pesticides, especially neonicotinoids, reduce pollinator foraging, reproductive success, and death. Climate change affects plant and pollinator distribution and phenology, which may disturb synchronization and pollination efficiency. The Varroa mite in honeybees and other illnesses and parasites worsen pollinator loss. Insect infestations, however, reduce agricultural production. Aphids, caterpillars, and beetles eat on leaves, stems, roots, and fruits, reducing yields and quality. Economic costs from insect pests are huge, with billions spent on pest management. Pest infestations can also propagate plant diseases and exacerbate environmental stress. Chemical pesticides are effective, yet they cause environmental pollution, health dangers, and pesticide-resistant insect populations. Insects play two roles, therefore agricultural management must promote beneficial insect activity while controlling pests. IPM solutions provide a holistic approach to this equilibrium. IPM uses biological management, habitat alteration, resistant crop types, and insecticides sparingly to control pest populations while protecting non-target creatures like pollinators. Natural enemies like predators, parasites, and diseases lower pest populations in biological management. Flower strips and hedgerows may help pollinators and natural enemies thrive in agriculture. Pollinator populations and sustainable agriculture depend on pollinator habitat conservation and restoration. Wildflower strips, cover crops, and diverse agricultural systems can increase pollinator feeding and nesting locations. Reduced pesticide use and organic farming can also protect pollinators and other vital insects. Subsidies and technical support for pollinator-friendly farming can help mainstream these practices. Pollinator conservation and pest management depend on public awareness and education. Raising knowledge about pollinators and pesticides and habitat loss can increase customer demand for pollinator-friendly products and activities. Farmers, agricultural extension professionals, and the public may learn about IPM, pollinator protection, and agricultural biodiversity through educational programs. Farmers, academics, politicians, and conservation groups must work together to develop and execute successful insect-agriculture methods. Understanding insect-plant interactions and establishing sustainable agricultural technology and practices requires research and innovation. Research into pollinator and pest ecology and behaviour can help build focused management methods to improve pollination services and reduce pest effects. Precision agriculture employs modern technologies to monitor crop health and insect populations, improving pest management efficiency and efficacy. Sustainable agricultural systems can benefit from crop breeding strategies that increase pest resistance and insect compatibility.



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