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Pollination and evolution of plant and insect interaction

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Abstract
Flowers exploit insects to achieve pollination; at the same time insects exploit flowers for food. Insects and flowers are a partnership. Each insect group has evolved different sets of mouthparts to exploit the food that flowers provide. From the insects' point of view collecting nectar or pollen is rather like fitting a key into a lock; the mouthparts of each species can only exploit flowers of a certain size and shape. This is why, to support insect diversity in our gardens, we need to plant a diversity of suitable flowers. It is definitely not a case of 'one size fits all'. While some insects are generalists and can exploit a wide range of flowers, others are specialists and are quite particular in their needs. In flowering plants, pollen grains germinate to form pollen tubes that transport male gametes (sperm cells) to the egg cell in the embryo sac during sexual reproduction. Pollen tube biology is complex, presenting parallels with axon guidance and moving cell systems in animals. Pollen tube cells elongate on an active extracellular matrix in the style, ultimately guided by embryo sac signals. A recognition system occurs between pollen grains and the stigma. Complex mechanisms act to precisely target the sperm cells into the embryo sac. These events initiate double fertilization in which the two sperm cells fuse to produce products.

Keywords: Pollination, Evolution, Reproduction, Double fertilization, Bees

Introduction

The process by which pollen is transferred to the female reproductive organs of a plant, thereby enabling fertilization to take place is known as pollination. Like all living organisms, seed plants have a single major goal: to pass their genetic information on to next generation. The reproductive unit is the seed, and the pollination is a process through which it is produced in all spermatophytes. For the process of pollination to be successful, a pollen grain produced by the anther, the male part of a flower, must be transferred to a stigma, the female part of the flower, of a plant of the same species. The process is rather different in angiosperms (flowering plants) from what it is in gymnosperms (other seed plants). In angiosperms, after the pollen grain has landed on the stigma, it creates a pollen tube which grows down the style until it reaches the ovary. Sperm cells from the pollen grain then move along the pollen tube enter the egg cell through the micropyle and fertilize it, resulting in the production of a seed.

A successful angiosperm pollen grain (gametophyte) containing the male gametes is transported to the stigma, where it germinates and its pollen tube grows down the style to the ovary. Its two gametes travel down the tube to where the gametophyte (s) containing the female gametes are held within the carpel. One nucleus fuses with the polar bodies to produce the endosperm tissues, and the other with the ovule to produce the embryo [1, 2]. Hence the term: "double fertilization". In gymnosperms, the ovule is not contained in a carpel, but exposed on the surface of a dedicated support organ, such as the scale of a cone, so that the penetration of carpel tissue is unnecessary. Details of the process vary according to the division of gymnosperms in question. Two main modes of fertilization are found in gymnosperms. Cycads and *Ginkgo* have motile sperm that swim directly to the egg inside the ovule, whereas conifers and gametophytes have sperm that are unable to swim but are conveyed to the egg along a pollen tube.

The study of pollination brings together many disciplines, such as botany, horticulture, entomology and ecology. The pollination process as an interaction between flower and pollen vector was first addressed in the 18th century by Christian Konrad Sprengel. It is important in horticulture and agriculture, because fruiting is dependent on fertilization: the result of pollination. The study of pollination by insects is known as *anthecology*.

Process of Pollination

Pollen germination has three stages; Hydration, Activation and Pollen tube emergence.

Hydration: The pollen grain is severely dehydrated so that its mass is reduced enabling it to be more easily transported from flower to flower. Germination only takes place after rehydration, ensuring that premature germination does not take place in the anther. Hydration allows the plasma membrane of the pollen grain to reform into its normal bilayer organization providing an effective osmotic membrane. The interaction between pollen and stigma is the first event in plants that initiates the process leading to fertilization. Mature pollen grains of angiosperms are always desiccated to some extent at the time of dispersal. The water content varies among different species, with most values ranging from 15 to 35% fresh weight. The state of dehydration is associated with an almost inactive metabolism. By contrast, uptake of water allows the development of osmotic pressure and the regaining of an active metabolism. The time needed for rehydration of the pollen on the stigma may vary greatly depending on the species; for example, 15 min in *Arabidopsis thaliana* and more than 60 min in *Brassica oleracea*.

Activation: Activation involves the development of actin filaments throughout the cytoplasm of the cell, which eventually become concentrated at the point from which the pollen tube will emerge. Hydration and activation continue as the pollen tube begins to grow [3].

Pollen tube growth: In conifers, the reproductive structures are borne on cones. The cones are either pollen cones (male) or ovulate cones (female), but some species are monoecious and others dioecious. A pollen cone contains hundreds of micro-sporangia carried on (or borne on) reproductive structures called sporophylls. Spore mother cells in the micro-sporangia divide by meiosis to form haploid microspores that develop further by two mitotic divisions into immature male gametophytes (pollen grains). The four resulting cells consist of a large tube cell that forms the pollen tube, a generative cell that will produce two sperm by mitosis, and two prothallial cells that degenerate. These cells comprise a much reduced micro-gametophyte, which is contained within the resistant wall of the pollen grain [4, 5].

The pollen grains are dispersed by the wind to the female, ovulate cone that is made up of many overlapping scales (sporophylls, megasporophylls), each protecting two ovules, each of which consists of a mega-sporangium (the nucellus) wrapped in two layers of tissue, the integument and the cupule, that were derived from highly modified branches of ancestral gymnosperms. When a pollen grain lands close enough to the tip of an ovule, it is drawn in through the micropyle (pore in the integuments covering the tip of the ovule) often by means of a drop of liquid known as a pollination drop. The pollen enters a pollen chamber close to the nucellus, and there it may wait for a year before it germinates and forms a pollen tube that grows through the wall of the mega-sporangium (i.e. nucellus) where fertilization takes place. During this time, the megaspore mother cell divides by meiosis to form four haploid cells, three of which degenerate. The surviving one develops as a megaspore and divides repeatedly to form an immature female gametophyte (egg sac). Two or three archegonia containing an egg then develop inside the gametophyte. Meanwhile, in the spring of the second year two sperm cells are produced by mitosis of the body cell of the male gametophyte. The pollen tube elongates and pierces and grows through the mega-sporangium wall and delivers the sperm cells to the female gametophyte inside. Fertilization takes place when the nucleus of one of the sperm cells enters the egg cell in the mega-gametophyte's archegonium [5].

In flowering plants, the anthers of the flower produce microspores by meiosis. These undergo mitosis to form male gametophytes, each of which contains two haploid cells. Meanwhile, the ovules produce megaspores by meiosis, further division of these form the female gametophytes, which are very strongly reduced, each consisting only of a few cells, one of which is the egg. When a pollen grain adheres to the stigma of a carpel it germinates, developing a pollen tube that grows through the tissues of the style, entering the ovule through the micropyle. When the tube reaches the egg sac, two sperm cells pass through it into the female gametophyte and fertilization takes place [4].

Abiotic pollination

Hydrophily and anemophily

Abiotic pollination refers to situations where pollination is mediated without the involvement of other organisms. The most common form of abiotic pollination, anemophily, is pollination by wind. Wind pollination is very imprecise, with a minute proportion of pollen grains landing by chance on a suitable receptive stigma, the rest being wasted in the environment. This form of pollination is used by grasses, most conifers, and many deciduous trees. Hydrophily is pollination by water, and occurs in aquatic plants which release their pollen directly into the surrounding water. About 80% of all plant pollination is biotic [6]. In gymnosperms, biotic pollination is generally incidental when it occurs, though some gymnosperms and their pollinators are mutually adapted for pollination.

Entomophily

The best-known examples probably are members of the order Cycadales and associated species of beetles. Of the abiotically pollinated species of plant, 98% are anemophilous and 2% hydrophilous. It is thought that among angiosperms, entomophily is the primitive state; this is indicated by the vestigial nectaries in the wind-pollinated *Urtica* and other plants, and the presence of fragrances. Of the angiosperms, grasses, sedges, rushes and catkin-bearing plants are in general wind pollinated. Other flowering plants are mostly biotic, the pollen being carried by animal vectors. However, a number of plants in multiple families have secondarily adopted wind pollination in contrast to other members of their groups. Some plants are intermediate between the two pollination methods. Common Heather is regularly pollinated by insects, but produce clouds of pollen and some wind pollination is inevitable, and the hoary plantain is primarily wind pollinated, but is also visited by insects which pollinate it [7].

More commonly, the process of pollination requires pollinators: organisms that carry or move the pollen grains from the anther of one flower to the receptive part of the carpel or pistil (stigma) of another. This is biotic pollination [8]. The various flower traits that differentially attract one type of pollinator or another are known as pollination syndromes. At least 100,000 species of animal, and possibly as many as 200,000, act as pollinators of the estimated 250,000 species of flowering plants in the world [6]. The majority of these pollinators are insects, but about 1,500 species of birds and mammals have been reported to visit flowers and may transfer pollen between them. Besides birds and bats which are the most frequent visitors, these include monkeys, lemurs, squirrels, rodents and possums [6]. Insect pollinators such as honeybees (*A. mellifera*) [12], bumblebees (*B. terrestris*) [13, 14], and butterflies (*Thymelicus flavus*) [15] have been observed to engage in flower constancy, which means they are more likely to transfer pollen to other conspecific plants [16, 17]. This can be beneficial for the pollinators, as flower constancy prevents the loss of pollen during interspecific flights and pollinators from clogging stigmas with pollen of other flower species. It also improves the probability that the pollinator will find productive flowers easily accessible and recognisable by familiar clues [18].

Entomophily, pollination by insects, often occurs on plants that have developed colored petals and a strong scent to attract insects such as, bees, wasps and occasionally ants (Hymenoptera), beetles (Coleoptera), moths and butterflies (Lepidoptera), and flies (Diptera). The existence of insect pollination dates back to the dinosaur era [10].

Zoophily

In this the process of the pollination is performed by vertebrates such as birds and bats, particularly, hummingbirds, sunbirds, spiderhunters, honeyeaters, and fruit bats. Plants adapted to using bats or moths as pollinators typically have white petals and a strong scent and flower at night, whereas plants that use birds as pollinators tend to produce copious nectar and have red petals [11].

Mechanism: Cross-pollination, also called *allogamy*, occurs when pollen is delivered from the stamen of one flower to the stigma of a flower on another plant of the same species. Plants adapted for cross-pollination [4] have several mechanisms to prevent self-pollination; the reproductive organs may be arranged in such a way that self-fertilisation is unlikely, or the stamens and carpels may mature at different times [4].

Self-pollination occurs when pollen from one flower pollinates the same flower or other flowers of the same individual [19]. It is thought to have evolved under conditions when pollinators were not reliable vectors for pollen transport, and is most often seen in short-lived annual species and plants that colonize new locations [20]. Self-pollination may include *autogamy*, where pollen is transferred to the female part of the same flower; or *geitonogamy*, when pollen is transferred to another flower on the same plant [21]. Plants adapted to self-fertilize often have similar stamen and carpel lengths. Plants that can pollinate themselves and produce viable offspring are called self-fertile. Plants that cannot fertilize themselves are called self-sterile, a condition which mandates cross-pollination for the production of offspring [21].

Cleistogamy: is self-pollination that occurs before the flower opens. The pollen is released from the anther within the flower or the pollen on the anther grows a tube down the style to the ovules. It is a type of sexual breeding, in contrast to asexual systems such as apomixis. Some *cleistogamous* flowers never open, in contrast to *chasmogamous* flowers that open and are then pollinated. Cleistogamous flowers are by necessity found on self-compatible or self-fertile plants [22]. Although certain orchids and grasses are entirely cleistogamous, other plants resort to this strategy under adverse conditions. Often there may be a mixture of both cleistogamous and chasmogamous flowers, sometimes on different parts of the plant and sometimes in mixed inflorescences. The ground bean produces cleistogamous flowers below ground, and mixed cleistogamous and chasmogamous flowers above [23].

An estimated 48.7% of plant species are either dioecious or self-incompatible obligate out-crossers [24, 25]. It is also estimated that about 42% of flowering plants exhibit a mixed mating system in nature. In the most common kind of mixed mating system, individual plants produce a single type of flower and fruits may contain self-pollinated, out-crossed or a mixture of progeny types.

Pollinator and pollinizers

Pollination also requires consideration of pollenizers. The terms "pollinator" and "pollenizer" are often confused: a *pollinator* is the agent that moves the pollen, whether it be bees, flies, bats, moths, or birds; a *pollenizer* is the plant that serves as the pollen source for other plants. Some plants are *self-compatible* (*self-fertile*) and can pollinate and fertilize themselves. Other plants have chemical or physical barriers to self-pollination.

In agriculture and horticulture pollination management, a good pollenizer is a plant that provides compatible, viable and plentiful pollen and blooms at the same time as the plant that is to be pollinated or has pollen that can be stored and used when needed to pollinate the desired flowers. Hybridization is effective pollination between flowers of different species, or between different breeding lines or populations e.g., Heterosis.

Peaches are considered self-fertile because a commercial crop can be produced without cross-pollination, though cross-pollination usually gives a better crop. Apples are considered self-incompatible, because a commercial crop must be cross-pollinated. Many commercial fruit tree varieties are grafted clones, genetically identical. An orchard block of apples of one variety is genetically a single plant. Many growers now consider this a mistake. One mean of correcting this mistake is to graft a limb of an appropriate polarizer (generally a variety of crabapple) every six trees or so.

Pollen vectors

Biotic pollen vectors are animals, usually insects, but also reptiles, birds, mammals, and sundry others, that routinely transport pollen and play a role in pollination. This is usually as a result of their activities when visiting plants for feeding, breeding or shelter. The pollen adheres to the vector's body parts such as face, legs, mouthparts, hair, feathers, and moist spots; depending on the particular vector. Such transport is vital to the pollination of many plant species.

Any kind of animal that often visits or encounters flowers is likely to be a pollen vector to some extent. For example, a crab spider that stops at one flower for a time and then moves on, might carry pollen incidentally, but most pollen vectors of significant interest are those that routinely visit the flowers for some functional activity. They might feed on pollen, or plant organs, or on plant secretions such as nectar, and carry out acts of pollination on the way. Many plants bear flowers that favour certain types of pollinator over all others. This need not always be an effective strategy, because some flowers that are of such a shape that they favor pollinators that pass by their anthers and stigmata on the way to the nectar, may get robbed by ants that are small enough to bypass the normal channels, or by short-tongued bees that bite through the bases of deep corolla tubes to extract nectar at the end opposite to the anthers and stigma. Some flowers have specialized mechanisms to trap pollinators to increase effectiveness [26]. Other flowers will attract pollinators by odor. For example, bee species such as *Euglossa cordata* are attracted to orchids this way, and it has been suggested that the bees will become intoxicated during these visits to the orchid flowers, which last up to 90 minutes [27]. However, in general, plants that rely on pollen vectors tend to be adapted to their particular type of vector, for example day-pollinated species tend to be brightly coloured, but if they are pollinated largely by birds or specialist mammals, they tend to be larger and have larger nectar rewards than species that are strictly insect-pollinated. They also tend to spread their rewards over longer periods, having long flowering seasons; their specialist pollinators would be likely to starve if the pollination season were too short [28].

As for the types of pollinators, reptile pollinators are known, but they form a minority in most ecological situations. They are most frequent and most ecologically significant in island systems, where insect and sometimes also bird populations may be unstable and less species-rich. Adaptation to a lack of animal food and of predation pressure, might therefore favour reptiles becoming more herbivorous and more inclined to feed on pollen and nectar [28]. Most species of lizards in the families that seem to be significant in pollination seem to carry pollen only incidentally, especially the larger species such as Varanidae and Iguanidae, but especially several species of the Gekkonidae are active pollinators, and so is at least one species of the Lacertidae, *Podarcis lilfordi*, which pollinates various species, but in particular is the major pollinator of *Euphorbia dendroides* [30, 31] on various Mediterranean islands [29].

Mammals are not generally thought of as pollinators, but some rodents, bats and marsupials are significant pollinators and some even specialise in such activities. In South Africa certain species of *Protea* are adapted to pollination by rodents and elephant shrews. The flowers are borne near the ground, are yeasty smelling, not colourful, and sunbirds reject the nectar with its high xylose content [32].The mice apparently can digest the xylose and they eat large quantities of the pollen. Examples of pollen vectors include many species of wasps, that transport pollen of many plant species, being potential or even efficient pollinators [33].

Evolution of early plant and insect pollinator interaction

The first fossil record for abiotic pollination is from fern plant in the late of Gymnosperms which showed the evidence for biotic pollination as early as the Triassic period. Many fossilized pollen grains show characteristics similar to the biotically dispersed pollen today. Furthermore, the gut contents, wing structures, and mouthpart morphologies of fossilized beetles and flies suggest that they acted as early pollinators. The association between beetles and angiosperms during the early Cretaceous period led to parallel radiations of angiosperms and insects into the late Cretaceous. The evolution of nectaries in late Cretaceous flowers signals the beginning of the mutualism between hymenopterans and angiosperms.

Bees provide a good example of mutualism that exists between hymenopterans and angiosperms. Flowers provide bees with nectar (an energy source) and pollen (a source of protein) [35]. When bees go from flower to flower collecting pollen they are also depositing pollen grains onto the flowers, thus pollinating them. While pollen and nectar, in most cases, are the most notable reward attained from flowers, bees also visit flowers for other resources such as oil, fragrance, resin and even waxes. It has been estimated that bees originated with the origin or diversification of angiosperms [36]. In addition, cases of coevolution between bee species and flowering plants have been illustrated by specialized adaptations. For example, long legs are selected for in *Rediviva neliana* [30], a bee that collects oil from *Diascia capsularis*, which have long spur lengths that are selected for in order to deposit pollen on the oil-collecting bee, which in turn selects for even longer legs in *R. neliana* and again longer spur length in *D. capsularis* is selected for, thus, continually driving each other's evolution [37, 38].

In agriculture

An Andrena bee collects pollen among the stamens of a rose. The female carpel strcture appears rough and globular to the left. The bee’s stash of pollen is on its hind leg. *Bombus ignites*, a popular pollinator in Japan and China pollinates Blueberries. Bumble bee hives need to be bought each year as the queen must hibernate. They are used nonetheless as they offer advantage with certain fruits blueberries. Well-pollinated blackberry blossom begins to develop fruit. Each incipient drupelet has its own stigma and good pollination requires the delivery of many grains to the flower so that all drupelet develop. Pollination management is a branch of agriculture that seeks to protect and enhance present pollinators and often involves the culture and addition of pollinators in monoculture situations, such as commercial fruit orchards. The largest managed pollination event in the world is in Californian almond orchards, where nearly half (about one million hives) of the US honey bees are trucked to the almond orchards each spring. New York's apple crop requires about 30,000 hives; Maine's blueberry crop uses about 50,000 hives each year.

Bees are also brought to commercial plantings of cucumbers, squash, melons, strawberries, and many other crops. Honey bees are not the only managed pollinators: a few other species of bees are also raised as pollinators. The alfalfa leafcutter bee is an important pollinator for alfalfa seed in western United States and Canada. Bumblebees are increasingly raised and used extensively for green house tomatoes and other crops.

The ecological and financial importance of natural pollination by insects to agricultural crops, improving their quality and quantity, becomes more and more appreciated and has given rise to new financial opportunities. The vicinity of a forest or wild grasslands with native pollinators near agricultural crops, such as apples, almonds or coffee can improve their yield by about 20%. The benefits of native pollinators may result in forest owners demanding payment for their contribution in the improved crop results -a simple example of the economic value of ecological services. Farmers can also raise native crops in order to promote native bee pollinator species as shown with *L. vierecki* [39] in Delaware and *L. leucozonium* [40] in southwest Virginia.

World view and benefits of insect pollination

The American Institute of Biological Sciences reports that native insect pollination saves the United States agricultural economy nearly an estimated $3.1 billion annually through natural crop production [41]; pollination produces some $40 billion worth of products annually in the United States alone [42].

Pollination of food crops has become an environmental issue, due to two trends. The trend to monoculture means that greater concentrations of pollinators are needed at bloom time than ever before, yet the area is forage poor or even deadly to bees for the rest of the season. The other trend is the decline of pollinator populations, due to pesticide misuse and overuse, new diseases and parasites of bees, clear cut logging, decline of beekeeping, suburban development, removal of hedges and habitat from farms. Wide spread aerial spraying for mosquitoes due to West Nile fears is causing an acceleration of the loss of pollinators.

The US solution to the pollinator shortage, so far, has been for commercial beekeepers to become pollination contractors and to migrate. Just as the combine harvesters follow the wheat harvest from Texas to Manitoba, beekeepers follow the bloom from south to north, to provide pollination for many different crops. In some situations, farmers or horticulturists may aim to restrict natural pollination to only permit breeding with the preferred individuals plants. This may be achieved through the use of pollination bags.

Improving pollination in areas with suboptimal bee densities

In some instances growers' demand for beehives far exceeds the available supply. The number of managed beehives in the US has steadily declined from close to 6 million after WWII, to less than 2.5 million today. In contrast, the area dedicated to growing bee-pollinated crops has grown over 300% in the same time period. Additionally, in the past five years there has been a decline in winter managed beehives, which has reached an unprecedented rate of colony losses at near 30% [43-46]. At present, there is an enormous demand for beehive rentals that cannot always be met. There is a clear need across the agricultural industry for a management tool to draw pollinators into cultivations and encourage them to preferentially visit and pollinate the flowering crop. By attracting pollinators like honeybees and increasing their foraging behavior, particularly in the center of large plots, we can increase grower returns and optimize yield from their plantings. ISCA Technologies [47], from Riverside California, created a semio-chemical formulation called SPLAT Bloom that modifies the behavior of honeybees, inciting them to visit flowers in every portion of the field.

Environmental impacts on insect pollinators

Loss of pollinators, also known as Pollinator decline (of which colony collapse disorder is most well known) has been noticed in recent years [48].

Observed losses would have significant economic impacts. For the insect pollinator decline the habitat destruction [48], pesticide, parasitism/diseases and climate change are responsible, and many researchers believe it is the synergistic effects of these factors which are ultimately detrimental to pollinator populations.

The structure of plant-pollinator network

Wild pollinators often visit a large number of plant and grass species and plants are visited by a large number of pollinator species. All these relations together form a network of interactions between plants and pollinators. Surprising similarities were found in the structure of networks consisting out of the interactions between plants and pollinators. This structure was found to be similar in very different ecosystems on different continents, consisting of entirely different species.

The structure of plant-pollinator networks may have large consequences for the way in which pollinator communities respond to increasingly harsh conditions. Mathematical models, examining the consequences of this network structure for the stability of pollinator communities suggest that the specific way in which plant-pollinator networks are organized minimizes competition between pollinators and may even lead to strong indirect facilitation between pollinators when conditions are harsh. This means that pollinator species together can survive under harsh conditions. But it also means that pollinator species collapse simultaneously when conditions pass a critical point. This simultaneous collapse occurs, because pollinator species depend on each other when surviving under difficult conditions.

Such a community-wide collapse, involving many pollinator species, can occur suddenly when increasingly harsh conditions pass a critical point and recovery from such a collapse might not be easy. The improvement in conditions needed for pollinators to recover, could be substantially larger than the improvement needed to return to conditions at which the pollinator community collapsed.

Coevolution

History

The insect-pollinated flowers of angiosperms use a combination of cues such as bright colours and streaked pattern to adverse to insects. The early spermatophytes (seed plants) were largely dependent on the wind to carry their pollen from one plant to another, and it was around 125 to 115 million years ago that a new pollination strategy developed and angiosperms (flowering plants) first appeared [49]. Before that, insect involvement in pollination was limited to "pollination assistants", insects which inadvertently carried the pollen between plants merely by their movements. The real relationship between plants and insects began with the arrival of the first angiosperms in the Early Cretaceous. The morphology of the first fossil basal angiosperms has similarity to modern-day plants that are fertilised by beetles. It seems likely that beetles led the way in insect pollination, followed by flies. Among the twelve living families of basal angiosperms, six are predominantly pollinated by flies, five by beetles and only one by bees. Nevertheless, traits such as sapromyophily (emitting the odour of carrion to attract flies) have evolved independently in several unrelated angiosperm families.

The plant's needs

Wind and water pollination require the production of vast quantities of pollen because of the chancy nature of its deposition. If they are not to be reliant on the wind or water (for aquatic species), plants need pollinators to move their pollen grains from one plant to another. They particularly need pollinators to consistently choose flowers of the same species, so they have evolved different lures to encourage specific pollinators to maintain fidelity to the same species. The attractions offered are mainly nectar, pollen, fragrances and oils. The ideal pollinating insect is hairy (so that pollen adheres to it), and spends time exploring the flower so that it comes into contact with the reproductive structures.

Mechanisms

Many insects are pollinators, particularly bees, Lepidoptera, wasps, flies, ants and beetles [50]. Few plants are generalists, being pollinated by insects in several orders. The entomophilous plant species have frequently evolved mechanisms to make themselves more appealing to insects, e.g., brightly coloured or scented flowers, nectar, or appealing shapes and patterns. Pollen grains of entomophilous plants are generally larger than the fine pollens of anemophilous (wind-pollinated) plants, which has to be produced in much larger quantities because such a high proportion is wasted. This is energetically costly, but in contrast, entomophilous plants have to bear the energetic costs of producing nectar.

Butterflies and moths have hairy bodies and long proboscides which can probe deep into tubular flowers [51]. Butterflies mostly fly by day and are particularly attracted to pink, mauve and purple flowers. The flowers are often large and scented, and the stamens are so-positioned that pollen is deposited on the insects while they feed on the nectar. Moths are mostly nocturnal and are attracted by night-blooming plants. The flowers of these are often tubular, pale in colour and fragrant only at night. Hawkmoths tend to visit larger flowers and hover as they feed; they transfer pollen by means of the proboscis. Other moths land on the usually smaller flowers, which may be aggregated into flower heads. Their energetic needs are not so great as those of hawkmoths and they are offered smaller quantities of nectar. Inflorescences pollinated by beetles tend to be flat with open corollas or small flowers clustered in a head with multiple, projecting anthers that shed pollen readily. The flowers are often green or pale-coloured, and heavily scented, often with fruity or spicy aromas, but sometimes with odours of decaying organic matter. Some, like the giant water lily, include traps designed to retain the beetles in contact with the reproductive parts for longer periods.

Unspecialized flies with short proboscis are found visiting flowers of fruit crops with readily accessible nectar [52]. More specialised flies like syrphids and tabanids can visit more advanced blooms, but their purpose is to nourish themselves, and any transfer of pollen from one flower to another happens haphazardly. The small size of many flies is often made up for by their abundance, however they are unreliable pollinators as they may bear incompatible pollen, and lack of suitable breeding habitats may limit their activities. Some *Pterostylis* orchids are pollinated by midges unique to each species. A decline, for whatever reason, to one side of this partnership can be catastrophic for the other. Flowers pollinated by bees and wasps vary in shape, colour and size. Yellow or blue plants are often visited, and flowers may have ultra-violet nectar guides, that help the insect to find the nectary. Some flowers, like sage or pea, have lower lips that will only open when sufficiently heavy insects, such as bees, land on them. With the lip depressed, the anthers may bow down to deposit pollen on the insect's back. Other flowers, like tomato, may only liberate their pollen by buzz pollination, a technique in which a bumblebee will cling on to a flower while vibrating its flight muscles, and this dislodges the pollen. Because bees care for their brood, they need to collect more food than just to maintain themselves, and therefore are important pollinators. Other bees are nectar thieves and bite their way through the corolla in order to raid the nectary, in the process bypassing the reproductive structures. Ants are not well adapted to pollination but they have been shown to perform this function in *Polygonum cascadense* and in certain desert plants with small blossoms near the ground with little fragrance or visual attraction, small quantities of nectar and limited quantities of sticky pollen.

Plant-insect pairings

Some plant species co-evolved [50] with a particular pollinator species, such as the bee orchid. The species is almost exclusively self-pollinating in its northern ranges, but is pollinated by the solitary bee *Eucera* in the Mediterranean area. The plant attracts these insects by producing a scent that mimics the scent of the female bee. In addition, the lip acts as a decoy, as the male bee confuses it with a female that is visiting a pink flower. Pollen transfer occurs during the ensuing pseudo-copulation. Figs of genus Ficus have a mutualistic arrangement with certain tiny agaonid wasps. In the common fig, the inflorescence is a syconium, formed by an enlarged, fleshy, hollow receptacle with multiple ovaries on the inner surface. A female wasp enters through a narrow aperture, fertilises these pistillate flowers and lays its eggs in some ovaries, with galls being formed by the developing larvae. In due course, staminate flowers develop inside the syconium. Wingless male wasps hatch and mate with females in the galls before tunnelling their way out of the developing fruit. The winged females, now laden with pollen, follow, flying off to find other receptive syconia at the right stage of development. Most species of fig have their own unique commensal species of wasp insects.

The status and decline of insect pollinators

In Europe: It is estimated that 84% of EU crops (valued at £12.6 billion) and 80% of wildflowers rely on insect pollination. Across Europe 38% of bee and hoverfly species are in decline, and only 12% are increasing. 24% of Europe's bumblebees are believed to be facing extinction according to one report.

In USA: 57 species of bees and 58 species of butterflies and moths are on Red List -these are species that are seriously endangered or believed extinct.

In UK: The 2/3 of the Moths are in decline trend. “Lost” (possibly extinct) insect species include: Bordered gothic moth *Heliophobus reticulata marginosa*; Orange upperwing moth *Jodia croceago*; Brigton wainscot Moth *Oria musculosa*; Over 75% of the 59 UK butterflies are declining and 5 extinct. 3 species of bumblebee have become extinct, 2 are critically endangered, and 10 are in very serious decline. Among them includes 5 species that were common in the 1980s.

Conclusion

A pollen grain is transported to the stigma, where it germinates and its pollen tube grows down the style to the ovary. The gametes are held within the carpel and later produce the embryo. Many types of animals are responsible for this pollen transfer and act as part of the pollination process. Some of these include bats, birds and even land mammals, but the most common pollinators are insects. Insect pollination is crucial to most gardens and is as simple as insects like bees, butterflies and wasps flying from flower to flower in order to collect nectar. In the process, pollen collects on their bodies and rubs off on other flowers that they visit. This fertilizes the flower and the plant will then grow seeds and the fruit around the seeds. At present the insect pollinators are threatened by various implications. Therefore, we suggest that for the survival of the life on this planet, the conservation of the pollinators is important.

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