



REVIEW ARTICLE

Mosquito-mediated pollination: Exploring sensory cues, plant volatiles and ecological roles

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Abstract

Pollination is a fundamental biological process essential for plant reproduction, often mediated by biotic agents, a huge chunk of which is composed of different insect orders. Mosquitoes have been considered pests and vectors of several diseases, masking the fact of their contribution towards pollination; this review aims to reclaim the significance of mosquitoes as pollinating agents while giving brief information on various forms of entomophily. The interaction between plants and mosquitoes involves the role of various sensory cues that drive the mosquitoes towards the plants. The cues might be visual, which includes the colour of the flower or its UV reflection. They may also be olfactory through the different volatile compounds or semiochemicals that the plant may release to attract potential pollinators. Plants also produce certain volatiles through different mechanisms when faced with stress, such as herbivory, these volatiles, termed herbivory induced plant volatiles may also play a role in deterring insects that may serve as pollinators when released. This review identified several publications and evidence uncovered in research conducted on mosquitoes as pollinating agents and physio-chemical interactions with different plant and mosquito species while giving examples about different forms of entomophily and delving into plant defence strategies.

Keywords: *Aedes aegypti*; *Culex pipiens*; insects; olfactory cues; semiochemicals; visual cues; volatiles

Introduction

Pollination is an important process in a plant's life cycle and can be defined as "the transfer of pollen from the anther of a flower to the stigma of the same or another flower." This reproductive action commences the process of seed production in a plant (1, 2).

Most flowering plants rely on cross-pollination by vectors (wind, water or animals) to enhance genetic diversity. Insects are key pollinators in natural and agricultural ecosystems. Flies (order Diptera) alone comprise one of the largest groups of anthophilous insects and mosquitoes (a family within Diptera) visit flowers to feed on nectar (3). However, despite this potential, mosquito pollination has been largely overlooked in pollination biology (3, 4).

Mosquitoes are traditionally studied as pests and disease vectors, so their ecological roles have been neglected. Recent reviews note that we often view mosquitoes through an "anthropocentric lens" that ignores their non-disease interactions (4). Although floral visitation by mosquitoes has been recognised for over a century, rigorous studies of mosquito-plant interactions are scarce (3).

Understanding mosquito pollination is important because pollinator diversity gives us an idea about ecosystem resilience and crop yields, especially under environmental change (3, 4). If we ignore mosquitoes, we may miss obscure but ecologically significant pollination pathways (4). Novel mosquito-control strategies (e.g. sterile-male or *Wolbachia* releases) could drastically alter mosquito

populations. Recent work warns that we may be underestimating mosquito-flower mutualisms, so altering mosquito communities could have unexpected ripple effects on plants (4).

In summary, although mosquitoes are famous as vectors, they also perform ecosystem services (4). Given global pollinator declines, climate change and new genetic tools targeting mosquitoes, unravelling the "hidden lives" of mosquitoes as pollinators is an important frontier in ecology (3, 4).

This review examines the ecological role of mosquitoes as pollinators, with particular focus on the mechanisms underlying mosquito-mediated pollination and the various floral cues that facilitate mosquito attraction and visitation.

Insects as pollinators

Insects constitute a vast myriad of members that take part in different roles in the environment. From being voracious pests to important decomposers, insects play a very important part in the functioning of an ecosystem. Insects are also primary animal mediated pollinators as shown in Table 1 and contribute to pollination of over 80 % of wild plant species and 75 % of cultivated plant species across the world (5, 6). The common characteristics of plants that are entomophilous include an abundant pollen kit or device for pollen transport and presence of different kinds of attractants (7, 8). This includes pollen, nectar, plant oil, an odor that attracts insects (7).

Visual, thermal and motor attractions are also used (9, 10). Insects have different reasons for visiting plants, these reasons include: feeding on the plant parts, which include the soft and succulent blossom tissues, or as a source of nectar which is a key source of carbohydrates in many species and serves as an important growth factor in many species, or as an oviposition site. The reasons for these visits to the plant differ amongst the variety of insect orders but they often affect the pollination in those particular plants (11).

Depending on the order of the pollinator insect, the different types of entomophily include– cantharophily (beetles; Coleoptera), psychophily (butterflies; Lepidoptera) and phalaenophily (moths; Lepidoptera), hymenopter pollination (ants, bees and wasps; Hymenoptera) and myophily (Flies: Diptera) (11).

Mosquitoes as pollinating agents

Mosquitoes are often known to be notorious for their role as disease transmitters. The most significant of these is Malaria, transmitted by *Anopheles* mosquitoes. This disease is known to affect over 200 million people worldwide and causes an estimated 0.6 million to 1.2 million deaths annually (31). Another genus of mosquitoes, called *Aedes*, is responsible for carrying the yellow fever virus and dengue virus, which is a rising problem in the tropics and subtropics. Mosquitoes are also known to carry nematodes that spread elephantiasis. Other viruses carried by mosquitoes include viruses that cause various forms of encephalitis, chikungunya, rift valley fever and ross river fever. Mosquitoes are also known to affect various livestock and wild animals (31).

There are over 3500 mosquito species and only a small fraction of this number is known to carry pathogens. While most people assume that blood consists of the majority of a mosquito's daily diet, this assumption is untrue for the most part. Sugar is a key requirement in a mosquito's diet and newly emerged mosquitoes cannot survive for long without consuming a sugar meal (32). Female mosquitoes take up blood meals for egg development for certain protein components. The consumption of sugar aids female

mosquitoes in their search for blood by providing them with the necessary energy (32, 33). While female mosquitoes of most species need to rely on blood to lay eggs, both males and females rely on sugar as a source of energy (32). Plants, more specifically floral nectar, are the source for this sugar. Even though the term sugar is used, mosquitoes obtain significantly more than just carbohydrates from plants, deriving other nutrients from nectar (34). While both sexes participate in nectar feeding, male mosquitoes, unlike females, do not take blood meals and depend exclusively on floral sugars for survival, which makes their flower visitation rates significantly higher (34).

This habitual nectar feeding of mosquitoes may have a role in pollination. During the process of obtaining nectar, mosquitoes are able to pick up a small amount of pollen from the flower, thereby facilitating pollination in the process, even though there are not many cases (32).

Floral cues

Flowers exhibit a range of traits, collectively known as 'pollinator syndromes.' These traits are associated with the attraction and utilisation of a specific group of animals as pollinators (35, 36). They are the result of evolutionary processes, where plants have developed specific characteristics that correspond to the physiology and behaviour of their pollinators. These cues influence the shape, colour, odour, nectar composition and structure to attract and identify potential pollinators. There is also a constant evolution in these traits in response to pollinator abundance, insect physiology and floral stimuli (36).

In the case of mosquitoes, plants have adopted certain floral cues that aid in pollinator attraction. These include visual signals like the colour of the flower, a specific floral odour (olfactory cues), metabolic heat, nocturnal respiration of carbon dioxide and presence of chemical compounds (chemical cues). These factors enable the mosquitoes to locate and engage with the flowers, ensuring successful pollination (37).

Table 1. Different insect orders as pollinators

Pollination type	Definition	Examples and details
Cantharophily	Pollination carried out by beetles (order Coleoptera).	Beetles visit flowers attracted by distinct odours resembling decaying fruits, carrion, decayed fish, or the beetles themselves (11). The scents trigger the beetles' sexual instincts, inducing copulation and egg deposition (12). In this process, pollen is stuck on their body (13). <i>Magnolia</i> species are adapted for beetle pollination (14).
Psychophily	Pollination carried out by butterflies (order Lepidoptera).	Butterflies visit flowers for feeding purposes, specifically families with a proboscis like Nymphalidae, Hesperidae, Papilionidae, Lycaenidae, Pieridae (15). Some butterflies pollinate flowers based on specific colours (e.g., <i>Heliconius charithonia</i> is attracted to blue, blue-green, orange and red colours) (16).
Phalaenophily	Pollination carried out by moths (order Lepidoptera).	Moths pollinate pale coloured, strongly scented flowers with long and narrow floral parts (17, 18). An example is the coevolution of the <i>Yucca</i> moths and <i>Yucca</i> sp where moths are exclusive pollinators (19, 20).
Hymenopterophily	Pollination facilitated by insects from ants, wasps, bees (order Hymenoptera).	Ant pollination (Myrmecophily): Rare; observed in <i>Cytinus hypocistis</i> (Cytinaceae) (21, 22) Wasp pollination: Observed in <i>Eucomis autumnalis</i> and <i>Eucomis comosa</i> pollinated by <i>Hemipepsis pompilid</i> wasps attracted by floral scent (23). Bee pollination (Melittophily): Most common mode; examples include <i>Solanum lycopersicum</i> pollinated by <i>Bombus hypocrite</i> (24) and <i>Apis mellifera</i> , a globally important pollinator (Western honey bee) (25).
Myophily	Pollination carried out by flies (order Diptera)	Flies visit flowers for nectar, shelter, or oviposition sites. Example: <i>Nuphar subintegerrima</i> is pollinated by <i>Notiphila maritima</i> , a fly that uses the plant for oviposition (26, 27). <i>Dracula chimaera</i> is pollinated by flies from the genus <i>Zygothrica</i> . <i>Trollius europaeus</i> is pollinated by <i>Chiastocheta</i> flies (28–30). Flies also assist in mutualism with plants in locating mates.

Visual cues

Visual cues influence pollinating insects by targeting their vision. Floral colour is one of the most important visual traits exhibited to attract pollinators. Displaying certain colours is responsible for setting off positive reactions in various floral visitors. These traits undergo constant change to increase the rate of efficiency of the pollinator and thereby promoting pollination of the unpollinated flowers. Floral shape is another important visual indicator (38).

Similarly, nectar host flowers for mosquitoes had one thing in common for the most part, they were all found to be light or pale in colour. In the case of diurnal pollination, it was noticed that mosquitoes were particularly attracted towards dull and colourless flowers. The basis of visual attraction towards the flowers seemed to depend on the reflectance rather than the wavelength of light (39). The shape of the flower did not hold much relevance in mosquito pollination (40).

A study conducted on mosquito pollination by *Aedes aegypti* and *Culex pipiens* in *Tanacetum vulgare* (Tansy) revealed that human visible colours on an inflorescence may not affect mosquito foraging, however aspects such as contrast within or between an inflorescence and its surroundings can be significant. UV floral reflections may guide nectar-foraging mosquitoes, as observed in other insect pollinators (37).

To check the effectiveness of visual inflorescence cues, inflorescences of *T. vulgare* were either covered, which left pollinator *C. pipiens* to rely only on olfactory cues, or left uncovered, which gave both visual and olfactory cues. It was observed that more mosquitoes went towards the uncovered inflorescences proving the contribution of visual cues towards the overall attractiveness. These results were expected as it is a known phenomenon that mosquitoes rely on visual cues even when finding a vertebrate host for a blood meal (41, 42). However, these cues if present with other cues such as olfactory or CO₂ emission from the host improve the overall attraction (42).

Another key observation was that female *C. pipiens* mosquitoes preferred UV dark inflorescence models over UV dark yellow inflorescence models. This supports the significance of UV floral reflectance as a prominent visual cue. This attraction can also imply that mosquitoes tend to get attracted towards targets that reflect relatively less light. This phenomenon is analogous to attraction of mosquitoes towards UV absorbing dark plumage of its hosts (42).

Olfactory cues

Olfactory cues play an important role in chaperoning plant-pollinator interactions. Floral odour is a key factor in providing necessary information to pollinators. Flower odour may vary upon pollination and is also dependent on the age of the flower (38). Plant-pollinator interaction dependent on an olfactory basis can be generalised or highly specific in order to give better reproductive success. Floral scents are produced in plants by an array of different chemicals (43). These chemicals have different functions (attractants, repellents, protection, etc.) and are responsible for giving the flower its distinct odour and for attracting pollen vectors, they are commonly termed as floral volatile organic compounds (FVOCs). The FVOCs are mainly of 3 types: terpenoids, benzenoids or phenylpropanoids and fatty acid derivatives. Olfactory cues and chemical cues go hand in hand and are both crucial for alluring pollinators (43). Studies have proven that odour emitted through the

help of floral FVOCs are perceived by pollinators before colour, proving the fact that olfactory floral cues alone can enhance plant-pollinator interactions. However, the presence of multimodal floral cues can improve the efficiency of the pollination process (43).

Likewise, flower odour was an important factor in attracting mosquitoes; Mosquitoes have a very sensitive olfactory system that helps them to locate essential nutrient sources including nectar (44). An experiment on *A. aegypti* that involved exposing them to floral extracts concluded that the mosquitoes were particularly drawn to the models containing the floral extracts and steered away from the control setups; this study demonstrated that FVOCs are believed to be used by mosquitoes to locate potential nectar sources (45).

Platanthera obtusata was discovered to undergo pollination with mosquitoes facilitating the process (46). He observed yellow pollinia of the plant stuck on the mosquito specimens collected and all the specimens collected were found to be female. Most of the mosquitoes caught had one or two, with a maximum of 4 pollinia stuck on its eyes (Fig. 1). To prove his hypothesis that mosquitoes were in fact the pollinators, a few of the plants and grew them in a jar; later introduced mosquitoes into the jar (46). After leaving the setup undisturbed for a few days, the mosquitoes were collected and saw that all of the specimens had pollinia stuck on its eyes. This came to be the first recorded instance of mosquito pollination and over the years extensive research has been conducted on this interaction (46). Later, *Aedes communis* and *Aedes canadensis* were recorded pollinating the flowers. The mechanism of attraction was suspected to be related to the scent and nectar of the flowers (47).

This mechanism related to attraction based on scent and nectar was further proven in a study that investigated the olfactory basis of mosquito pollination in *P. obtusata* (44). The mosquitoes were able to locate the rather inconspicuous flowers and even managed to land on flowers that were bagged. The pollination process involved probing of the nectar spur or nectar consumption that resulted in pollinia attachment to the eye (44). *Platanthera obtusata* pollinated by mosquitoes were found to emit nonanal and octanal odours and low concentrations of terpene compounds, namely; linalool and lilac aldehyde (44). In order to test if the floral volatiles of *P. obtusata* attracted these mosquitoes, the behavior of *Aedes increpitus* and *A. communis* in response to scent emitted by *P. obtusata* were gauged (44). It was found that the mosquitoes had strong antennal responses to the natural floral scent and an artificial mixture composed of the floral volatiles. However, when lilac aldehyde was removed from these mixtures, the attraction was found to have a considerable decrease (44).

To study the perception of odours of *P. obtusata* by the mosquitoes, the changes in its antennal lobe, which is the centre for olfaction in mosquitoes were investigated (44). It was found out that odour stimulation caused distinct changes in glomerular patterns specifically in the anterior-medial glomeruli and anterior-lateral glomeruli and evoked strong flight responses (44). The anterior-medial glomeruli were found to be sensitive towards terpene compounds in both *A. increpitus* and *A. aegypti*. Particularly in *A. aegypti*, the AM2 glomeruli showed a strong response to lilac aldehyde (44). When different odour cues were given to mosquitoes, such as human scent, a different glomerular pattern was observed. The ratio of concentration of nonanal odours and lilac aldehyde played a crucial role in harbouring mosquitoes to the flowers (44). This can be seen as an instance of pollinator specificity as mosquitoes exclusively pollinate *P. obtusata* and no

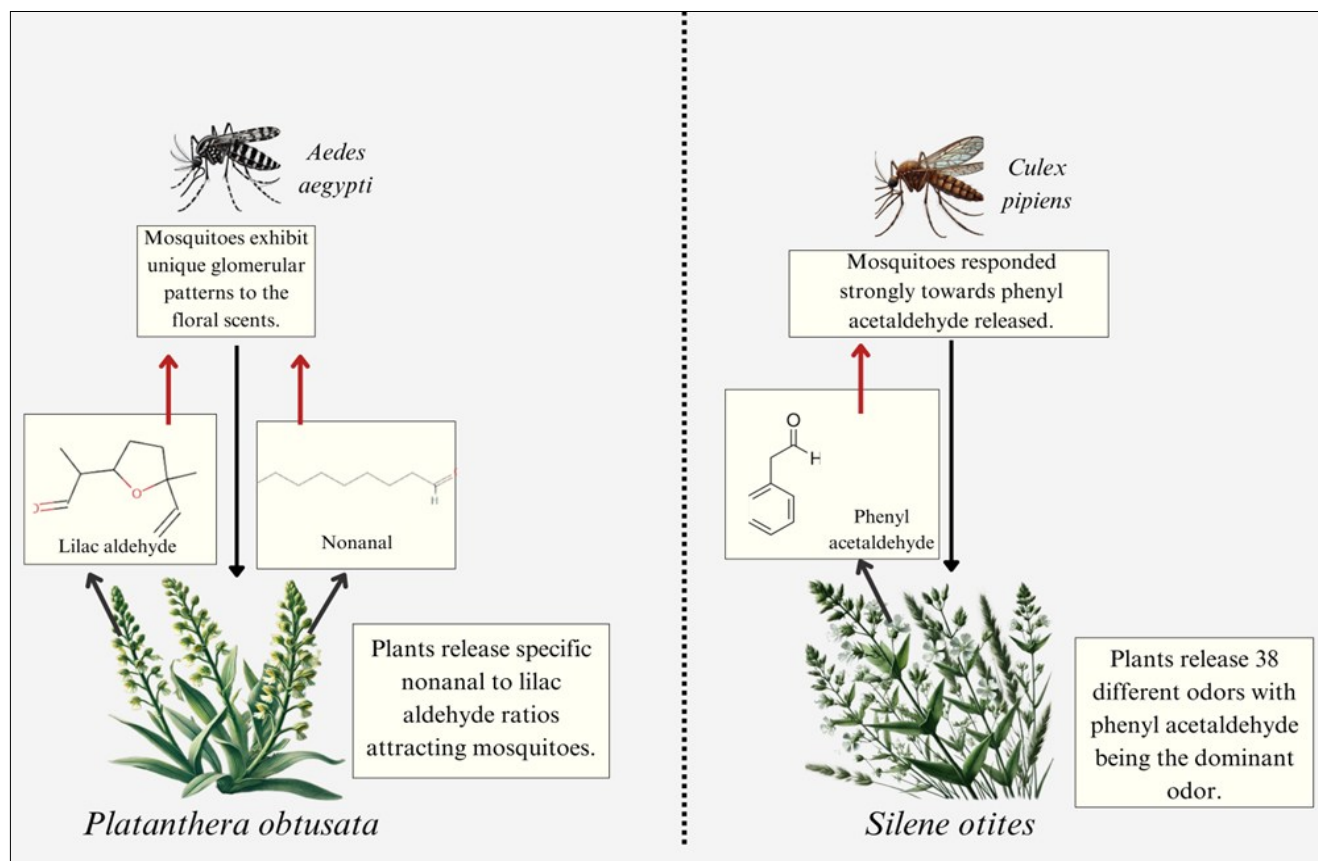


Fig. 1. Pictorial representation of pollination in *Platanthera obtusata* and *Silene otites* by mosquitoes with the help of olfactory cues.

other *Platanthera* species as the concentrations of the plant volatiles are significantly different (44). The mosquitoes exhibited a much stronger response when exposed to *P. obtusata* odours, particularly in the AM2 and LC2 glomeruli as compared to response to other *Platanthera* scents, which caused changes only in the AM2 glomeruli (44). Overall, this study suggested that specific ratios of plant volatiles were crucial in attracting mosquitoes to *P. obtusata* and these ratios suggest why the pollinating mosquitoes prefer one orchid species over the other (44).

Mosquito pollination is well known in the plant *Silene otitis* St.-Lag., which was revealed in a study conducted in 1976 to identify the potential entomophilic pollinators of the plant (48). The study identified mosquitoes and a few lepidopterans serving as the plant's pollen vectors. It was observed that mosquitoes took over the role of pollination when the conditions were adverse for the lepidopterans and vice versa. The nocturnal scent released by *S. otitis* seemed to play a role in attracting the mosquitoes (48). This was proven in a study that gauged the different floral odours released by *S. otitis* and their attractiveness to *C. pipiens*, which were its pollinators (49). It revealed that there were 38 different odours released by *S. otitis*, out of which *C. pipiens* responded strongly towards phenyl acetaldehyde, which was the dominant and most abundant odour. Whereas moths, which constituted the other pollinator group, were attracted to a wide array of different chemicals released by the flowers, mosquitoes showed a strong affinity only towards phenyl acetaldehyde. Even in the absence of visual cues, mosquitoes showed attraction towards the inflorescences based on their scent (49).

Mosquito mediated pollination by *C. pipiens* (common house mosquitoes) was hypothesised to occur in *T. vulgare* (Tansy) inflorescences (Fig. 2). It was observed that *C. pipiens* were frequent floral visitors to *T. vulgare* (Tansy) in the field, the visiting mosquitoes were collected and pollen was found stuck to their body parts,

moreover 75 % of the males and 78 % of female mosquitoes tested positive for containing fructose, indicating nectar feeding (50). To test if the mosquitoes were pollinating or just visiting the flowers as nectar thieves, the same experiment was carried out in the lab with laboratory reared mosquitoes. It was found that *C. pipiens* successfully carried out pollination by transferring pollen in between two inflorescences hence proving that *C. pipiens* are effective pollinators (50). It was suspected that floral semiochemicals which are chemicals that are produced by plants that elicit a response from individuals of same or different species, in this case pollinators, provided olfactory signals to *C. pipiens* that caused them to visit *T. vulgare* (Tansy) (50, 51). This hypothesis was proven by another study that dealt with understanding the multimodal floral cues offered to visiting mosquitoes using *T. vulgare* (Tansy) as the model plant (37). It was revealed that an increase in the CO₂ emission by the plant triggered an elevated attraction toward the plant by the pollinator mosquitoes (37). It has been known that CO₂ serves as an important sensory cue for mosquito attraction towards humans (37). With respect to a human-mosquito interaction, CO₂ is assumed to initiate mosquito take off and flight, increase the attractiveness of host odorants at a close range and act as an activator for mosquito responses to host semiochemical, visual and thermal signals (37). This similar concept is applicable towards nectar foraging of mosquitoes, after the sun sets, most plants halt their photosynthesis and produce CO₂ as a by-product of respiration and there is a subsequent release of CO₂ from the surrounding soil organisms, leading to a significant increase in CO₂ concentrations (37). Even though this alone may not have triggered any response from the mosquito, it was observed that the increased rates of CO₂ played a role in enhancing the attractiveness of odorants released by the flowers to the mosquitoes by activating the mosquitoes response to olfactory cues (37).

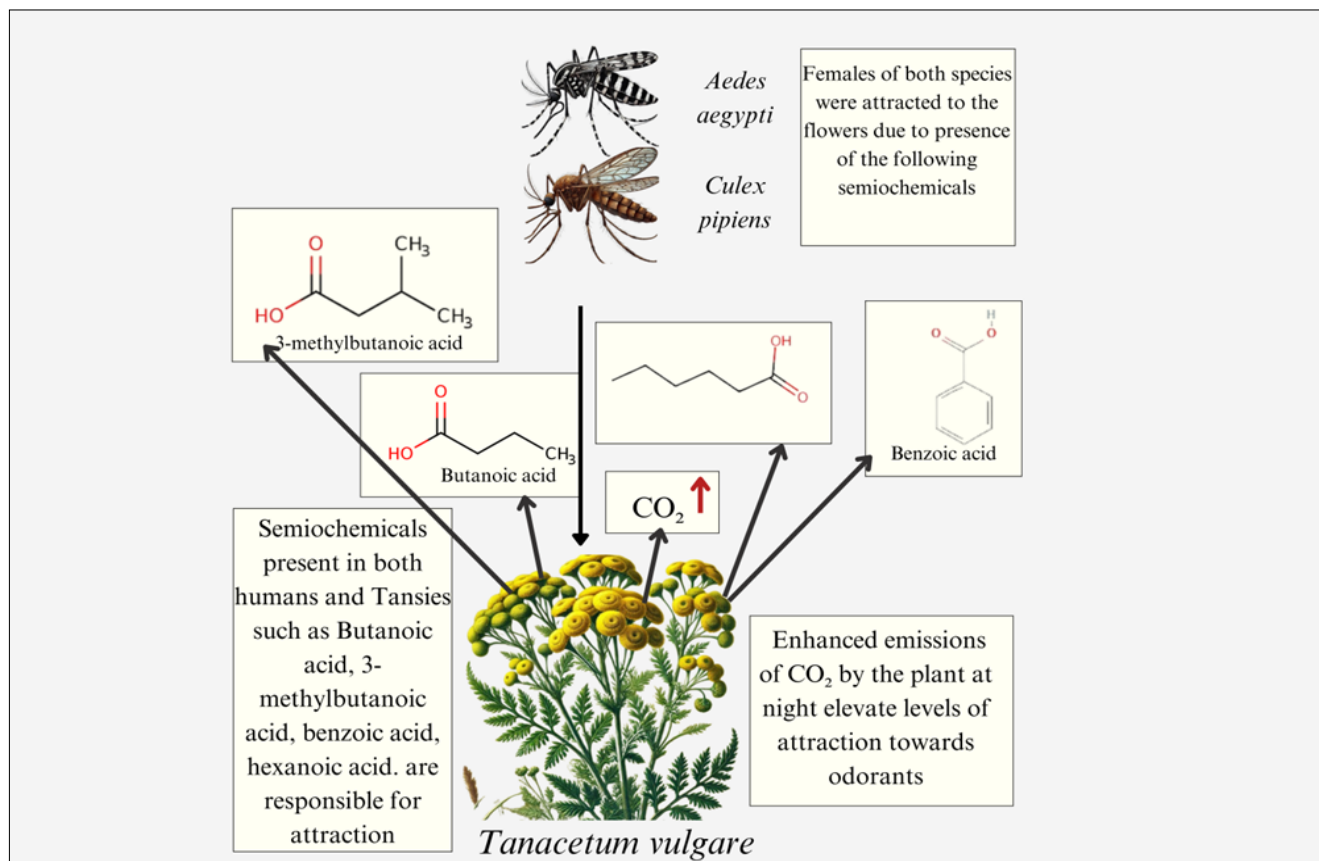


Fig. 2. Pictorial representation of pollination in *Tanacetum vulgare* by mosquitoes with the help of olfactory cues.

Certain semiochemicals present in *T. vulgare* (Tansy) were also found to be present in humans and these were known to be responsible for attracting female *A. aegypti* and older female *C. pipiens* which appear to have shifted from nectar to host foraging (37). Some of these shared semiochemicals present in both humans and Tansies that are proven to be both nectar foraging and host foraging cues include: butanoic acid, 3-methylbutanoic acid, benzoic acid, and hexanoic acid (37).

Plant volatiles: adaptive response to physiological stress and herbivore defense

Volatile organic compounds (VOCs) are carbon based solids and liquids that are capable of vaporising to gas phase at 0.01 kPa near 20 °C (52). It consists of a huge range of chemical substances produced by all life forms and is an important medium for communication between organisms and their environment through emission and perception (53). Plants also produce VOCs as a result of biotic or abiotic interactions such as for defence and pollinator attraction, these consist of a wide range of volatile compounds produced through many biochemical pathways and is one of the most important secondary metabolites produced by plants (54). The VOCs help plants in natural habitats tackle a wide range of biotic stresses, such as those caused by fungi, pests, microbes, etc., which are controlled through varied mechanisms of defence constituting molecular, morphological and biochemical aspects; such manifestations are known to trigger herbivore-induced VOCs which many plants increasingly emit as a defence response against herbivory (Fig. 3). This emission happens naturally through systemic, redox, jasmonic, signalling responses, etc. that results in allelopathic responses enhancing altered transcriptions of defence-related genes provoking insect deterrents, attract parasitoids and causing behavioural changes in plants during herbivory (55, 56). An example of which can be seen in leeks (*Allium porrum* Georgi) where the

production of alk(en)yl-cysteine sulfoxides is found to increase significantly when under attack of *Acrolepiopsis assectella* (55).

Specifically, herbivory induces leaf volatiles as monoterpenoids, farnesene, methyl jasmonate, caryophyllene, bergamotene and ocimene-through-pathways known as herbivore-induced plant volatiles (HIPVS), one of which is the lipoxygenase pathway that is recorded to stay for hours after induction (56). Such mechanisms of defence occur when olfactory receptors (ORs) receive odorant binding proteins that help stabilise and transport odours through a seven-membrane topology, forming a heterodimer and co-receptor called Orco releasing bio-fumigants that confer resistance to mechanical damage and harm (57, 58).

In plants, the major VOCs are terpenoids that are synthesised through 2 independent pathways, the mevalonic and methylerythritol pathways, that form volatile sesquiterpenes, hemiterpenes, monoterpenes and diterpenes, which are precursor compounds (59).

Conclusion

Pollination is essential in providing genetic diversity in plants. There are various forms of pollination including those mediated by organisms termed as pollinating agents. Insects of numerous different orders are known to contribute towards this effort, with a total of over 80 % of plants being pollinated entomologically. Mosquitoes' role as vectors for diseases has long been a stifle to their indulgence in their ecological significance as a pollinating agent. Mosquito mediated pollination involves a range of fascinating aspects that are far more complex than previously assumed. Their dependency on sugar makes foraging flowers a counting factor in the evolution of floral physiology and biochemical aspects. Many cues provide information on how the whole interaction between mosquitoes and plants work; these factors have also far evolved

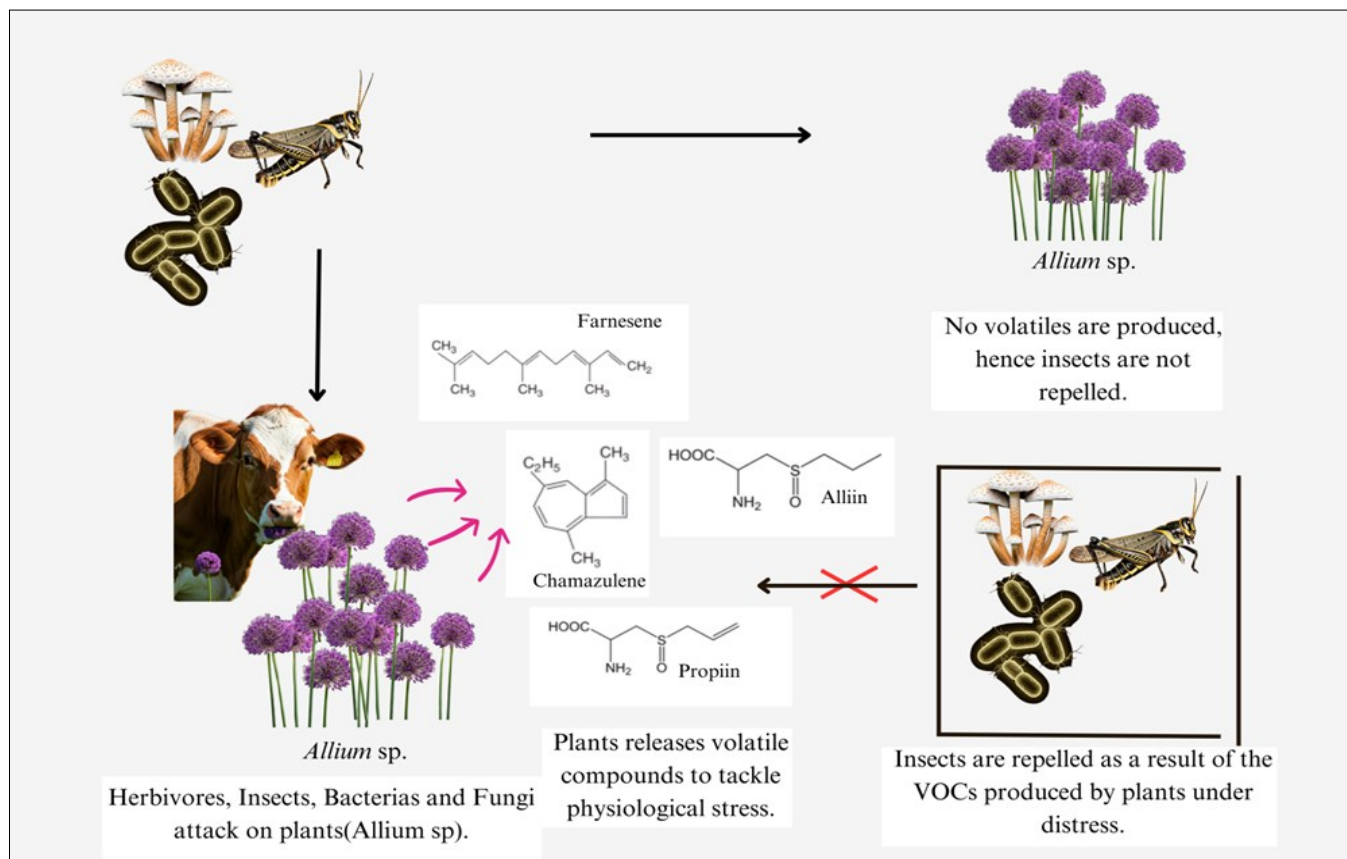


Fig. 3. Repellent mechanism of plant volatiles over herbivory.

through time with variable changes in forms of interactions of mosquitoes concerning floral colour, odour, reflectance of UV, etc, in accordance with its pollinators.

Despite this, mosquito pollination remains an understudied domain. Significant gaps exist in our knowledge of mosquito foraging behavior, plant specificity and pollination efficiency. While it is essential to note the significance of the various ill impacts borne by mosquitoes, this review predominantly deals with providing a greater perspective on their role as pollinators rather than just a menace. Future research that integrates aspects of behavioral ecology, molecular biology and conservation science can offer valuable insights into this overlooked pollinator group. Understanding mosquitoes beyond their menace could uncover novel aspects of plant pollinator networks and enrich our knowledge of co-evolutionary dynamics.

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Authors' contributions

MT, SNK, DT carried out the conceptualisation and finalisation of the review article. AD participated in the modifications, corrections and drafted the manuscript. AKB and DKV carried out the corrections and subtopic distributions throughout the manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Abrol DP. Pollination biology. Dordrecht: Springer Netherlands; 2012. <http://link.springer.com/10.1007/978-94-007-1942-2>
2. Ramírez F, Kallarackal J, Feijoa [*Acca sellowiana* (O. Berg) Burret] pollination: a review. *Sci Hortic.* 2017;226:333–41. <https://doi.org/10.1016/j.scienta.2017.08.054>
3. Foster WA. Mosquito pollination of plants: an overview of their role and an assessment of the possible contribution of disease vectors. *Transgenic Res.* 2024;33(5):297–322. <https://doi.org/10.1007/s11248-024-00394-w>
4. Shannon DM, Richardson N, Lahondère C, Peach D. Mosquito floral visitation and pollination. *Curr Opin Insect Sci.* 2024;65:101230. <https://doi.org/10.1016/j.cois.2024.101230>
5. Choi SW, Jung C. Diversity of insect pollinators in different agricultural crops and wild flowering plants in Korea: literature review. *J Apic.* 2015;30(3):191. <https://doi.org/10.17519/apiculture.2015.09.30.3.191>
6. Hussain M, Liaqat H, Malik MF, Aftab K, Batool M, Iqbal R, et al. Distribution patterns of insect pollinator assemblages at Deva Vatala National Park, Bhimber, Azad Jammu and Kashmir. *Pak J Zool.* 2024;56(4). <https://researcherslinks.com/current-issues/Distribution-Patterns-of-Insect-Pollinator-Assemblages/20/1/8410/html> <https://doi.org/10.17582/journal.pjz/20221004171007>
7. Fægri K, Van Der Pijl L. Biotic pollination: principles. In: *Principles of pollination ecology.* Elsevier; 1979. p. 42–54. <https://linkinghub.elsevier.com/retrieve/pii/B9780080231600500116> <https://doi.org/10.1016/B978-0-08-023160-0.50011-6>
8. Pacini E. Ecologia della riproduzione. *Ecol Végétale.* 1995;200–15.

9. Fægri K, Van Der Pijl L. Biotic pollination: primary attractants. In: Principles of pollination ecology Elsevier; 1979. p. 55–76. <https://linkinghub.elsevier.com/retrieve/pii/B9780080231600500128> <https://doi.org/10.1016/B978-0-08-023160-0.50012-8>
10. Fægri K, Van Der Pijl L. Biotic pollination: secondary attractants. In: Principles of pollination ecology. Elsevier; 1979. p. 77–87. <https://linkinghub.elsevier.com/retrieve/pii/B978008023160050013X> <https://doi.org/10.1016/B978-0-08-023160-0.50013-X>
11. Fægri K, Van Der Pijl L. Animals as pollinators. In: Principles of pollination ecology. Elsevier; 1979. p. 96–133. <https://linkinghub.elsevier.com/retrieve/pii/B9780080231600500153> <https://doi.org/10.1016/B978-0-08-023160-0.50015-3>
12. Gottsberger G. Some aspects of beetle pollination in the evolution of flowering plants. In: Kubitzki K, editor. Flowering plants. Vienna: Springer Vienna; 1977. p. 211–26. http://link.springer.com/10.1007/978-3-7091-7076-2_14 https://doi.org/10.1007/978-3-7091-7076-2_14
13. Thien LB. Floral biology of *Magnolia*. Am J Bot. 1974;61(10):1037–45. <https://doi.org/10.1002/j.1537-2197.1974.tb12321.x>
14. Ishida K. Beetle pollination of *Magnolia praecocissima* var. *borealis*. Plant Species Biol. 1996;11(2–3):199–206. <https://doi.org/10.1111/j.1442-1984.1996.tb00146.x>
15. Reddi CS, Bai GM. Butterflies and pollination biology. Proc Anim Sci. 1984;93(4):391–6. <https://doi.org/10.1007/BF03186258>
16. Swihart CA, Swihart SL. Colour selection and learned feeding preferences in the butterfly, *Heliconius charitonius* Linn. Anim Behav. 1970;18:60–4. [https://doi.org/10.1016/0003-3472\(70\)90071-0](https://doi.org/10.1016/0003-3472(70)90071-0)
17. Basu S, Fernandez A. Bee conservation: beekeeping in the Philippines: status and success. 2022.
18. Kevan PG, Baker HG. Insects as flower visitors and pollinators. Annu Rev Entomol. 1983;28(1):407–53. <https://doi.org/10.1146/annurev.en.28.010183.002203>
19. Pellmyr O. Yuccas, Yucca moths and coevolution: a review. Ann Mo Bot Gard. 2003;90(1):35–55. <https://doi.org/10.2307/3298524>
20. Pellmyr O, Thompson JN, Brown JM, Harrison RG. Evolution of pollination and mutualism in the Yucca moth lineage. Am Nat. 1996;148(5):827–47. <https://doi.org/10.1086/285958>
21. De Vega C, Thorogood CJ, Albaladejo RG, Rakotonasolo F, Hobbhahn N, Martos F, et al. Evolutionary and ecological insights from *Cytinus*: a plant within a plant. Plants People Planet. 2025;7(2):308–17. <https://doi.org/10.1002/ppp3.10409>
22. De Vega C, Arista M, Ortiz PL, Herrera CM, Talavera S. The ant-pollination system of *Cytinus hypocistis* (Cytinaceae), a Mediterranean root holoparasite. Ann Bot. 2009;103(7):1065–75. <https://doi.org/10.1093/aob/mcp049>
23. Shuttleworth A, Johnson SD. A key role for floral scent in a wasp-pollination system in *Eucomis* (Hyacinthaceae). Ann Bot. 2009;103(5):715–25. <https://doi.org/10.1093/aob/mcn261>
24. Nayak RK, Rana K, Bairwa VK, Singh P, Bharti VD. A review on role of bumblebee pollination in fruits and vegetables. J Pharmacogn Phytochem. 2020;9(3):1328–34. <https://doi.org/10.22271/phyto.2020.v9.i3v.11494>
25. Khalifa SAM, Elshafiey EH, Shetaia AA, El-Wahed AAA, Algethami AF, Musharraf SG, et al. Overview of bee pollination and its economic value for crop production. Insects. 2021;12(8). <https://doi.org/10.3390/insects12080688>
26. Woodcock TS, Larson BMH, Kevan PG, Inouye DW, Lunau K. Flies and flowers II: floral attractants and rewards. J Pollinat Ecol. 2014;12:63–94. [https://doi.org/10.26786/1920-7603\(2014\)5](https://doi.org/10.26786/1920-7603(2014)5)
27. Peñalver E, Arillo A, Pérez-de la Fuente R, Riccio ML, Delclòs X, Barrón E, et al. Long-proboscid flies as pollinators of Cretaceous gymnosperms. Curr Biol. 2015;25(14):1917–23. <https://doi.org/10.1016/j.cub.2015.05.062>
28. Kearns CA. North American dipteran pollinators: assessing their value and conservation status. Conserv Ecol. 2001;5(1):art5. <https://doi.org/10.5751/ES-00262-050105>
29. Després L, Pettex E, Plaisance V, Pompanon F. Speciation in the globeflower fly *Chiastocheta* spp. (Diptera: Anthomyiidae) in relation to host plant species, biogeography and morphology. Mol Phylogenet Evol. 2002;22(2):258–68. <https://doi.org/10.1006/mpev.2001.1047>
30. Raguso RA. Don't forget the flies: dipteran diversity and its consequences for floral ecology and evolution. Appl Entomol Zool. 2020;55(1):1–7. <https://doi.org/10.1007/s13355-020-00668-9>
31. Godfray HCJ. Mosquito ecology and control of malaria. J Anim Ecol. 2013;82(1):15–25. <https://doi.org/10.1111/1365-2656.12003>
32. Hawkes FM, Hopkins RJ. The mosquito. In: Mosquitopia. London: Routledge; 2021. p. 16–31. <https://www.taylorfrancis.com/books/9781003056034/chapters/10.4324/9781003056034-3> <https://doi.org/10.4324/9781003056034-3>
33. De Swart MM, Balvers C, Verhulst NO, Koenraadt CJM. Effects of host blood on mosquito reproduction. Trends Parasitol. 2023;39(7):575–87. <https://doi.org/10.1016/j.pt.2023.04.003>
34. Upshur IF, Fehlman M, Parikh V, Vinauger C, Lahondère C. Sugar feeding by invasive mosquito species on ornamental and wild plants. Sci Rep. 2023;13(1):22121. <https://doi.org/10.1038/s41598-023-48089-2>
35. Fenster CB, Armbruster WS, Wilson P, Dudash MR, Thomson JD. Pollination syndromes and floral specialization. Annu Rev Ecol Evol Syst. 2004;35(1):375–403. <https://doi.org/10.1146/annurev.ecolsys.34.011802.132347>
36. Riffell JA. The neuroecology of insect-plant interactions: the importance of physiological state and sensory integration. Curr Opin Insect Sci. 2020;42:118–24. <https://doi.org/10.1016/j.cois.2020.10.007>
37. Peach DAH, Gries R, Zhai H, Young N, Gries G. Multimodal floral cues guide mosquitoes to tansy inflorescences. Sci Rep. 2019;9(1):3908. <https://doi.org/10.1038/s41598-019-39748-4>
38. Barragán, Fonseca KY, Van Loon JJA, Dicke M, Lucas, Barbosa D. Use of visual and olfactory cues of flowers of two brassicaceous species by insect pollinators. Ecol Entomol. 2020;45(1):45–55. <https://doi.org/10.1111/een.12775>
39. Foster WA. Mosquito sugar feeding and reproductive energetics. Annu Rev Entomol. 1995;40(1):443–74. <https://doi.org/10.1146/annurev.en.40.010195.002303>
40. Jepson PC, Healy TP. The location of floral nectar sources by mosquitoes: an advanced bioassay for volatile plant odours and initial studies with *Aedes aegypti* (L.). Bull Entomol Res. 1988;78(4):641–50. <https://doi.org/10.1017/S0007485300015492>
41. Liu MZ, Vosshall LB. General visual and contingent thermal cues interact to elicit attraction in female *Aedes aegypti* mosquitoes. Curr Biol. 2019;29(13):2250–7. <https://doi.org/10.1016/j.cub.2019.06.001>
42. Peach DAH, Ko E, Blake AJ, Gries G. Ultraviolet inflorescence cues enhance attractiveness of inflorescence odour to *Culex pipiens* mosquitoes. PLoS One. 2019;14(6):e0217484. <https://doi.org/10.1371/journal.pone.0217484>
43. Tandon R, Shivanna KR, Koul M, editors. Reproductive ecology of flowering plants: patterns and processes. Singapore: Springer Singapore; 2020. <https://link.springer.com/10.1007/978-981-15-4210-7> <https://doi.org/10.1007/978-981-15-4210-7>
44. Lahondère C, Vinauger C, Okubo RP, Wolff GH, Chan JK, Akbari OS, et al. The olfactory basis of orchid pollination by mosquitoes. Proc Natl Acad Sci. 2020;117(1):708–16. <https://doi.org/10.1073/pnas.1910589117>
45. Vargo AM, Foster WA. Responsiveness of female *Aedes aegypti* (Diptera: Culicidae) to flower extracts. J Med Entomol. 1982;19(6):710–8. <https://doi.org/10.1093/jmedent/19.6.710>
46. Dexter JS. Mosquitoes pollinating orchids. Science. 1913;37

- (962):867. <https://doi.org/10.1126/science.37.962.867.a>
47. Thien LB. Mosquito pollination of *Habenaria obtusata* (Orchidaceae). *Am J Bot.* 1969;56(2):232–7. <https://doi.org/10.1002/j.1537-2197.1969.tb07528.x>
 48. Brantjes NBM, Leemans JAAM. *Silene otites* (Caryophyllaceae) pollinated by nocturnal Lepidoptera and mosquitoes. *Acta Bot Neerl.* 1976;25(4):281–95. <https://doi.org/10.1111/j.1438-8677.1976.tb00240.x>
 49. Jhumur US, Dötterl S, Jürgens A. Floral odors of *Silene otites*: their variability and attractiveness to mosquitoes. *J Chem Ecol.* 2008;34(1):14–25. <https://doi.org/10.1007/s10886-007-9392-0>
 50. Peach DAH, Gries G. Nectar thieves or invited pollinators? A case study of tansy flowers and common house mosquitoes. *Arthropod Plant Interact.* 2016;10(6):497–506. <https://doi.org/10.1007/s11829-016-9445-9>
 51. Rico-Martínez R, Alvarado-Flores J, Pérez-Legaspi IA, Garza-León CV, Rivera-Dávila OL, Santos-Medrano GE, et al. Fate and adverse effects of pesticides in the environment. In: *Pesticides in the natural environment.* Elsevier; 2022. p. 65–119. <https://linkinghub.elsevier.com/retrieve/pii/B9780323904896000045> <https://doi.org/10.1016/B978-0-323-90489-6.00004-5>
 52. Abrahão MRE, Molina G, Pastore GM. Endophytes: recent developments in biotechnology and the potential for flavor production. *Food Res Int.* 2013;52(1):367–72. <https://doi.org/10.1016/j.foodres.2013.03.007>
 53. Bergman ME, Huang XQ, Baudino S, Caissard JC, Dudareva N. Plant volatile organic compounds: emission and perception in a changing world. *Curr Opin Plant Biol.* 2025;85:102706. <https://doi.org/10.1016/j.pbi.2025.102706>
 54. Picazo-Aragonés J, Terrab A, Balao F. Plant volatile organic compounds evolution: transcriptional regulation, epigenetics and polyploidy. *Int J Mol Sci.* 2020;21(23):8956. <https://doi.org/10.3390/ijms21238956>
 55. Dugravot S, Mondy N, Mandon N, Thibout E. Increased sulfur precursors and volatiles production by the leek *Allium porrum* in response to specialist insect attack. *J Chem Ecol.* 2005;31(6):1299–314. <https://doi.org/10.1007/s10886-005-5287-0>
 56. Kost C, Heil M. Herbivore-induced plant volatiles induce an indirect defence in neighbouring plants. *J Ecol.* 2006;94(3):619–28. <https://doi.org/10.1111/j.1365-2745.2006.01120.x>
 57. Conchou L, Lucas P, Meslin C, Proffit M, Staudt M, Renou M. Insect odorscapes: from plant volatiles to natural olfactory scenes. *Front Physiol.* 2019;10:972. <https://doi.org/10.3389/fphys.2019.00972>
 58. Razo-Belman R, Ozuna C. Volatile organic compounds: a review of their current applications as pest biocontrol and disease management. *Horticulturae.* 2023;9(4):441. <https://doi.org/10.3390/horticulturae9040441>
 59. Dudareva N, Klempien A, Muhlemann JK, Kaplan I. Biosynthesis, function and metabolic engineering of plant volatile organic compounds. *New Phytol.* 2013;198(1):16–32. <https://doi.org/10.1111/nph.12145>

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