Whispers in the Wind: The Impact of Chemical Communication on Insect Behavior and Pest Management

Vidya Madhuri E*, Rupali J S, Rajna S and Rittik Sarkar
Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi- 110012
*Corresponding Author: evidyamadhuri@gmail.com

Abstract

Chemical communication is crucial for insect survival, influencing behavior and interactions through semiochemicals. These chemicals, including allelochemicals, play diverse roles such as defense, attraction, and deterrence. Allelochemicals are categorized into allomones, kairomones, synomones, apneumones, and antimones, each affecting different aspects of interspecific communication. They are vital in ecological interactions and pest management, aiding in biological control by attracting natural enemies to pest-infested plants. This review highlights the significance of chemical signals in managing pest populations and supporting integrated pest management strategies.

Introduction

Chemical communication is a vital aspect of insect behavior, enabling them to interact and respond to their environment through chemical signals. Insects rely on the complexity of their chemical senses and the structures responsible for chemical signaling and perception to navigate their world. This form of communication is a predominant feature among insects, influencing their survival, reproduction, and interactions with other species. Semiochemicals are chemicals that carry messages between organisms for the purpose of communication. The term "semiochemical" comes from the Greek word semeion, meaning "signal." Introduced by Law and Regnier in 1971, semiochemicals encompass a wide range of chemical substances or mixtures released by an organism to evoke behavioral or physiological responses in other individuals. These chemicals play a crucial role in how insects perceive their environment and interact with each other, facilitating processes such as mating, foraging, and defense. Allelochemicals are a specific category of semiochemicals that are used in interspecific communication, where the chemical signal affects individuals of another species. The term "allelochemical," derived from the Greek allelon, meaning "of one another," was introduced by R. H. Whittaker in 1970. Allelochemicals are produced by one species and exert a physiological effect on individuals of a different species when released into the environment. These chemicals can impact the survival, growth, and development of both the emitting species and its natural enemies, highlighting their importance in ecological interactions and evolutionary adaptations. Allelochemicals are chemicals produced by an organism that exert physiological effects on individuals of another species when released into the environment. These substances play a crucial role in interspecific communication, influencing the survival, growth, and development of both the emitting organism and its natural enemies. Based on the nature of the behavioral responses they elicit, allelochemicals are categorized into several types: allomones, kairomones, synamones, apneumones, and antimones.

Allomones

Allomones are a type of allelochemical that benefits the emitter but not the receiver. The term "allomone" comes from the Greek words "allos," meaning "other," and "hormone," meaning "to excite." Introduced by Brown, Eisner, and Whittaker, allomones are primarily used for defensive purposes. These chemicals are designed to deter predators or competitors, enhancing the survival of the emitter. For example, citral, a mandibular secretion from many ants and bees, serves as a defensive compound. Similarly, formic acid in ants and sting gland secretions in bees are defensive allomones. Some beetles, such as bombardier beetles (Brachinus spp.) and vinegaroons (Mastigoproctus spp.), use allomones by spraying corrosive quinones, hydroquinones, or concentrated acetic acid at predators. Additionally, the larvae of certain butterflies in the family Papilionidae possess osmeteria, which produce defensive secretions. Allomones can be synthesized by the emitter or obtained from their food sources, such as the cardiac glycosides in monarch butterflies, which protect against avian predators and are acquired from milkweed plants consumed during larval development

Kairomones

Kairomones are chemicals that benefit the receiver but not the emitter. The term "kairomone" comes from the Greek word "kairos," meaning "opportunistic" or "exploitative." These substances are produced by one organism and trigger a behavioral or physiological response in individuals of another species, often to the advantage of the receiver. In many cases, phytophagous insects use kairomones to locate their host plants, identifying them through the chemical signatures of secondary plant substances.

For instance, the male sex pheromone of the southern green stink bug (*Nezara viridula*) acts as a kairomone by attracting the tachnid fly (*Trichopoda pennepes*), which uses the scent to find its host. Similarly, the parasitic mite *Varroa jacobsoni* is drawn to honey bee drone larvae by the fatty acid esters present in the larvae. Volatile compounds released from the larvae of *Drosophila* attract its parasites *Leptopilina heterotoma* and *L. fimbriata*. Another example is trichosane from the scales of *Heliothis* species, which lures the parasitoid *Trichogramma*. The release of heptanoic acid by the larva of the potato tuber moth (*Pthorimaea operculella*) enhances the searching behavior of its parasitoid. Additionally, α-farnesene secreted by the larva of the codling moth attracts its parasitoid. These interactions highlight how kairomones facilitate the ecological relationships between different species by exploiting chemical cues for survival and reproduction.

Synomones

Synomones are substances produced by an organism that elicit a behavioral or physiological response in another species, benefiting both the emitter and the receiver. These chemicals play a crucial role in mutualistic interactions. For example, herbivore-induced plant volatiles are considered active synomones, as they attract natural enemies of insect pests to the affected plants. This not only helps control pest populations but also benefits the plants by reducing damage. Synomones are also important in mate-finding communication, facilitating interactions between species in ways that are advantageous to both parties. Examples include floral scents that attract pollinating insects, such as honey bees, and the attraction of hymenopterous parasites in the genus *Trichogramma* to tomato plants, where they find suitable hosts to parasitize. Additionally, damaged pine trees emit terpenes that serve as kairomones for bark beetles to locate the trees. However, these same chemicals act as synomones by attracting pteromalid hymenopterous parasites that parasitize the beetles, thus benefiting both the parasitoids and the trees.

Apneumones

Apneumones are substances emitted by non-living materials that evoke a behavioral reaction in a receiving organism, which is favorable to the recipient but detrimental to the non-living material or an organism associated with it. The term "apneumone" comes from the Greek word "a-pneum," meaning "breathless" or "lifeless." An example of apneumones is the attraction of the ichneumonid parasite *Venturia canescens* by the smell of oatmeal, which is the food of its host. In this case, the apneumone benefits the parasitoid by leading it to a suitable habitat but is harmful to the host insect living on the oatmeal, a non-living material.

Antimones

Antimones are substances that result in maladaptive responses for both the emitter and the receiver. These chemicals, when encountered by another individual of a different species, induce a repellent reaction in both the emitting and receiving organisms. This mutual avoidance can be detrimental to both parties, as the repellent response discourages interactions that could have been beneficial in other contexts

Regurgitation and Defecation of Allelochemicals

In some insects, the intestines can expel ingested plant products through regurgitation, which may act as repellents to predators. For instance, the regurgitated allelochemicals from the hindgut can effectively repel ants. Similarly, when tactile stimulation occurs, the milkweed bug *Oncopeltus fasciatus* will defecate a solution containing repellent allelochemicals, specifically cardenolides. These defensive mechanisms help the insects protect themselves from predation and environmental threats.

Allelochemicals as Tissue Colorants

Allelochemicals can also function as tissue colorants in insects. For example, the white butterfly *Pieris brassicae* reared on its typical diet of cabbage leaves develops green pupae that blend with their background due to the high concentration of carotenoids, particularly lutein, in their cuticle. However, when these butterflies are reared on an artificial diet lacking carotenoids, their pupae exhibit a conspicuous turquoise blue coloration, making them highly visible to predators. This shift demonstrates how the presence or absence of allelochemicals can affect an insect's camouflage and survival.

Allelochemicals as Pheromonal Precursors

Allelochemicals can serve as precursors to pheromones, which are crucial for communication within and between species. For instance, bark beetles in the genera *Dendroctonus* and *Ips* convert hydrocarbons from their pine hosts into alcohols that function as aggregation or sex pheromones. Similarly, butterflies in the family *Nymphalidae* and moths in the family *Arctiidae* transform pyrrolizidine alkaloids (PAs) into sex pheromones. These PAs, collected from damaged plants, are integral to reproductive success, highlighting the importance of allelochemicals in sexual communication and mating.

Allelochemicals as Pheromonal Synergists

In some cases, allelochemicals act as pheromonal synergists, enhancing the effectiveness of pheromones. For example, the turnip aphid (*Lipahis erysimi*) produces an alarm pheromone primarily composed of (E)-B-Farnesene, which is weakly active on its own. However, this activity is significantly increased by allelochemicals that act as synergists, improving the alarm pheromone's effectiveness and aiding in the aphid's defense mechanisms.

Allelochemicals as Defensive Agents of Eggs

Insects often utilize allelochemicals as defensive agents for their eggs. These compounds may be sequestered in the eggs to offer protection against predators and pathogens. For instance, chrysomelid beetles feeding on willow and poplar sequester the toxic allelochemical salicin, which is used to fortify their eggs, thereby providing a defense mechanism for the developing larvae.

Allelochemicals as Allomonal Precursors

Some insects convert allelochemicals from their food plants into allomones, which are used for defense. Chrysomelid beetle larvae from the genera *Chrysomela* and *Phratora* feed on willow and poplar leaves containing salicin. The larvae convert salicin into salicylaldehyde and glucose, using salicylaldehyde for defense and glucose for growth. This conversion provides a dual benefit, enabling the beetles to store and secrete the defensive compound from their glands.

Augmentation of Natural Enemies by Allelochemicals

Allelochemicals play a significant role in the biological control of pests by influencing the behavior of natural enemies. Chemical signals from both the host arthropods (kairomones) and plants (allomones) are critical for parasitoids in locating their hosts. Volatiles released by plants in response to herbivore damage, known as herbivore-induced synomones, can attract parasitoids. Many plant allelochemicals, while toxic or repellent to herbivores, are attractive to parasitoids. For example, allyl isothiocyanates from crucifer plants attract the braconid parasitoid *Diaeretiella rapae*. Similarly, the terpenoid p-caryophyllene released by damaged cotton plants attracts the predatory green lacewing *Chrysoperla carnea*. Exposing parasitoids to allelochemicals before release, such as synthetic kairomones, can enhance their effectiveness in biological control. For instance, increased parasitization of California red scale by *Aphytis melinus* has been achieved by exposing its parasitoid *Aphelinus mali* to synthetic kairomones. However, not all attempts are successful; using borneol to attract the tachinid parasitoid *Cyzemis alibicans* to apple trees did not increase oviposition, highlighting the complexity of utilizing allelochemicals in pest management.

Conclusion

Chemical communication is fundamental for insect survival, enabling them to adapt their behavior to changes in their environment. Semiochemicals play a critical role in this communication by influencing interactions among insects through various chemical signals. The effectiveness of these semiochemicals is determined by their chemical nature, volatility, and persistence in the environment. Allelochemicals, which include allomones, kairomones, synomones, apneumones, and antimones, serve various functions such as defense mechanisms, repellency, and as precursors for pheromones. These compounds can act as deterrents to predators, attractors for parasitoids, or defensive agents for eggs, demonstrating their versatile roles in insect interactions. Herbivore-induced synomones are particularly significant as they enhance biological control by attracting natural enemies to pest-infested plants. These interactions highlight the importance of chemical communication in managing pest populations and supporting integrated pest management strategies.

References

Ali, M. F., & Morgan, E. D. (1990). Chemical communication in insect communities: A guide to insect pheromones with special emphasis on social insects. *Biological Reviews, 65*(3), 227-247.

Blum, M. S. (2008). Allelochemicals. In J. L. Capinera (Ed.), *Encyclopedia of Entomology*. Springer.

Klowden, M. J. (2013). *Physiological systems in insects*. Academic Press.

McNeil, J. N., Millar, J. G., & Chapman, R. (2012). Chemical communication: Pheromones and allelochemicals. In R. F. Chapman, S. J. Simpson, & A. E. Douglas (Eds.), *Insects: Structure and Function* (5th ed., pp. 857-900).

Saha, T., & Chandran, N. (2017). Chemical ecology and pest management: A review. *Int J Chem Stud*, *5*(6), 618-21.

Matthews, R. W., Matthews, J. R., Matthews, R. W., & Matthews, J. R. (2010). Chemical communication. *Insect Behavior: 2nd Edition*, 217-259.

Guerrero, A., & Reddy, G. V. (2023). Chemical Communication in Insects: New Advances in Integrated Pest Management Strategies. *Insects*, *14*(10), 799.

* * * * * * * *