Utilizing Semiochemicals for Pest Management Strategies

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Chemical messages that initiate various behavioral responses in the organisms are called semiochemicals. The term is derived from the Greek word simeone, meaning a mark or a signal. Chemical communication appears to be primary mode of information transfer in most groups' animals. A well-developed olfactory system enables perception of even very weak signals from potential mates and discrimination between acceptance and non-acceptance of host for feeding, mating and oviposition. Semiochemicals are organic compounds used by insects to convey specific chemical messages that modify behavior or physiology. The attraction of insects to plants and other host organisms involves the detection of specific Semiochemicals or specific ratios of Semiochemicals. The insects use Semiochemicals to mediate important behaviors such as mating, oviposition, and foraging for resources. The first semiochemical to be chemically characterized was the sex pheromone of the silkworm moth (*Bombyxmori*) in 1959. Semiochemicals are divided into intraspecific (pheromones) and interspecific (allelochemical) communication chemicals. Allelochemicals can be divided in to signals that benefits that benefit the receiver (kairomones), the emitter (allomones), or both (synomones). Pheromones are produced by one individual of a species that induce the behavior and physiological response in another individual of the same species. Pheromones consist of sex, aggregation, alarm, Recruitment, Recognition, oviposition-deterrent, Trial and royal pheromone that evolved for the communication on the basis of interaction of member of the community

Overview of semiochemicals

The classification of the semiochemicals has been described as follows

Pheromones

A substance that is secreted by an organism to the outside and causes a specific reaction in a receiving organism of the same species. Subsequently, pheromones have been classified into eight types:

Aggregation pheromones: These pheromones cause insects to aggregate or congregate at food sites, reproductive habits, and hibernation sites and prominent in some species of beetles. For example, the hemiterpene 3-methylbut-3-en-1-ol has been shown to be the aggregation pheromone for two beetle pests: *Polygraphus rufipennis* Kirby (Coleoptera: Curculionidae) and *Lasconotus intricatus* Kraus (Coleoptera:Zopheridae)

Alarm pheromones: These are common in social insects such as ants and bees and aphids, which are usually found to occur in aggregation. The function of this type ofpheromone is to raise alert in conspecifics, to raise a defense response and to initiate avoidance. Some examples are: sesquiterpene (*E*)-β-farnesene (EBF), germacrene A, and α-pinene which were shown to be the main components of the alarm pheromone of several important aphid species.

Oviposition-deterrent pheromones: discourage females from laying eggs in the same

resource of another female. Several fruit flies e.g. *Rhagoletis pomonella* Walsh (Diptera: Tephritidae) mark the surface of fruit after oviposition to prevent egg laying by other female flies (Prokopy *et al.* 1982). Interestingly, females of the parasitic wasp, *Diachasma alloeum* (Muesebeck) (Hymenoptera: Braconidae) which attack the maggots of two species of fruit-parasitic flies in the genus *Rhagoletis* lay a single egg in a fly maggot and subsequently deposit a deterrent across the fruit surface by their ovipositor to prevent other females from ovipositing into the marked blueberry, hawthorn, or apple fruit.

Recognition pheromones: Social insects like ants, bees and termites these are used to distinguish colony members from non-colony members. These pheromones are tended to be simple -straight or branched –chain hydrocarbons and are a blend of compounds. The termite egg recognition pheromone (TERP) has been one of the most important pheromones to be identified, which strongly evokes the egg-carrying and grooming behaviour of workers.

Sex pheromones: mediate interaction between sexes of the same species and are mainly produced by females to attract males. The first characterization of a sex pheromone was reported in the silk moth *Bombyx mori* L. Lepidoptera: Bombycidae) Gossyplure HF (Albany International) was the first registered pheromone product granted by the Environmental Protection Agency (EPA) in February 1978. It was used for the suppression of pink bollworm. The structure of the majority of known insect pheromones consists of: unbranched aliphatics of nine to eighteen carbons, more than three double bonds, and end with an acetate, alcohol or aldehyde functional group.An example of such a functional group of pheromones is the straight-chained lepidopteran pheromones(SCLPs).

Trail pheromones: guide social insects to distant food sources. Trail pheromones can have both recruitment and orientation effects. Recently,6-*n*-pentyl-2-pyrone was shown to be the maintrail pheromone for the myrmicine ant, *Pristomyrmexpungens* Mayr (Hymenoptera: Formicidae).

Recruitment pheromones: induce nestmates to leave the nest and migrate to a work site or vice versa. Recruitment pheromones are discharged from exocrine glands, which are anatomical structures often specialized for synthesis and secretion for example, terrestrial ants have wide glandular sources of recruitment pheromones (Dufour's gland, the pygidial glands, poison glands, sternal glands, hindgut and rectal glands). Pheromones from these sources can be readily seen deposited on a solid substrate. An important model to illustrate the recruitment mechanism is the red fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). The process begins when a foraging scout worker discovers a food source too large for it to carry back to the colony. The recruitment mechanism includes several sub-categories: (i) initial trail laying by the scout ant, (ii) attraction of additional workers to the scout ant, (iii) induction of the workers to follow the trail and (iv) trail orientation.

Royal pheromones: recently identified from subterranean royal termites as a wax- like hydrocarbon composed of only C and H atoms called "heneicosane". This pheromone enables workers to recognize patronage (kings and queens), there by maintaining the strain reproductive division.

Allelochemicals: substances which transmit chemical messages between different species, known as interspecific communication. Fundamentally, these are substances which are primarily emitted by individuals of one species and are understood by individuals of a different species. They have been divided into five categories: allomones,kairomones, synomones, antimonies and apneumones .

Allomones (from Greek "allos + hormone" = exciteothers): released from one organism that stimulate a response in an individual of another species. The response is beneficial to the emittere.g. poisonous allelochemicals. They can also be seen as a deterrent emitted by insects against their predators as a defense mechanism. Granular trichomes which cover plant leaves and stems release herbivore-deterring allomones under stress conditions as a defense process.These allomones are toxic for the herbivorous insect pests, e.g. nicotine from tobacco plant.

Kairomones (from Greek word "kairos" = opportunistic or exploitative): emitted by one organism that stimulate a response in an individualof another species. The response is beneficial to the recipient, e.g. orientation of predaceous checkered beetles (Coleoptera: Cleridae) towards the aggregation pheromone of their prey; bark beetle (Coleoptera: Curculionidae: Scolytinae). Kairomones may be allomones or pheromones depending on the circumstances. Attract their prey (male moths) by releasing attractant allomones which serve as sex pheromones emitted by female moths. Also, exudates of warm-blooded animals that pull blood-sucking insects towards their hosts serve as kairomones.

Synomones: beneficial to both the releaser and receiver. Examples include scents used by flowers to attract pollinating insects. Moreover, herbivore-induced plant volatiles are considered to be active synomones which recruit natural enemies of insect pests towards the affected plan. Also, synomones play an essential role in mate-finding communication. This role relies on the reduction of competition in the olfaction communication channel between closely related species with overlapping pheromone components. This advisable action is important in preventing exhaustion from the time and energy required for orientation towards heterospecifics.

Antimones: maladaptive for both the releaser and receiver. These substances produced or acquired by an organism that, when encountered by another individual of a different species in the natural environment, activate in the receiving individual a repellent response to the emitting and receiving individuals.

Apneumones (from Greek word "a-pneum" = breathless or lifeless): emitted by a non-living source, causing a favorable behavioral or physiological reaction to a receiving organism, but harmful to other species that may be found either in or on the non-living material. Apneumones were suggested by Nordlund and Lewis (1976). Rare cases of these allele chemicals have been found later in the literature e.g. hexanal and 2-methyl-2-butanol released from rabbit stools attracts sand fly females for oviposition.

Devices used for application of semiochemicals for controlling insect pests Emission of plums (blend) of semiochemical substances is key to optimizing their effect towards the target insect pest. Controlled-release systems (dispensers)are fundamental to achieving release rates that mimic the natural release. Two main types of devices were recorded for the application of different semiochemical products, retrievable and passive non-retrievable dispensers (EFSA 2016). A description of these devices follows:

Retrievable dispensers

A−Passive dispensers (extruded or reservoir): the semiochemical substances are continuously emitted into the air. B − Active dispensers: The semiochemical substance is released discontinuously from the device.

Passive non-retrievable products

A − Dispensers (biodegradable dispensers): the semiochemical is emitted continuously from the device.B − Dosable matrix dispensers: the semiochemical is enclosed in a matrix (e.g. sticky polymeric material) onto plants or another substrate at the site of use.C − Capsule suspension products: the semiochemical is formulated as a microencapsulation (commonly used for pheromone application that allows effective prolongation of releasing levels).D − Granular products (non-WDG): the semio chemical is formulated in a granular form.

Semiochemicals in the Pest Suppression

Various control strategies of insects used in pest management programs are based on semiochemicals and include: monitoring, mass trapping, lure and kill (attract-annihilate),

Lure-and-Infect and mating disruption. Pheromones are applied for controlling insect pests in two different ways: indirect control and direct control. Indirect control includes monitoring for quarantine and spray timing strategy, whereas direct control includes mass trapping and area-wide dissemination applications. Area-wide dissemination involves three strategies: disruption, attractant and attract-and-kill (lure and kill) which are widely used commercially. Pheromone traps are used for different purposes in pest management strategies. For example, pheromone-baited traps are used as attracticide or mating disruption techniques to prevent males from reproducing. Additionally, pheromone traps can explore information about the population such as sex ratio and mating status that is useful for determining the population phase which is subject to cyclical changes in population density.

Monitoring

Monitoring systems using semiochemicals, such as sex pheromones, aggregation pheromones, and kairomones, are crucial for managing pest populations and keeping them below economic threshold levels. These traps help detect low-density populations and monitor invasive species to prevent their spread. For example, kairomone-based traps are used to monitor *Rhizophagus grandis*, a predator of the spruce bark beetle (*Dendroctonus micans*). In the context of stored grain pests, multiple pheromones can be used in a single trap to monitor different species, such as sex pheromones for the almond moth (*Ephestia cautella*), Indian meal moth (*Plodia interpunctella*), and Khapra beetle (*Trogoderma granarium*), as well as aggregation pheromones for flour beetles like *Tribolium castaneum* and *Tribolium confusum*. These pheromones are often combined with food attractants to enhance trap effectiveness.

Monitoring can be useful in following ways

1. Detection of pest
2. Measurement of pest density
3. Assessment of density of natural enemies
4. Assessment of pest phenology
5. Assessment of effectiveness of mating disruption
6. Monitoring insecticide resistance
7. Decision support

Mass trapping

Mass trapping is a pest control strategy that uses semiochemical-based lures to attract and remove target pests from the environment, effectively reducing pest populations. This technique involves setting traps that capture either males or females, slowing population growth by lowering reproductive potential. Traps typically consist of lures fixed on sticky surfaces or in liquid holders, and require regular maintenance to prevent saturation. Mass trapping has been successfully used for controlling pests like the Japanese beetle (*Popillia japonica*), as well as in broader pest management efforts following initial monitoring steps.

Lure-and-Ki*ll*

Lure-and-Kill is a variation of mass trapping where insects are attracted to a semiochemical-based lure, but instead of being trapped, they come into contact with a toxicant and are killed. This method has been used to control various pests, including beetles, moths, and flies. A notable success is the control of the olive fly (*Bactrocera olea*) in Greece, where this strategy has proven effective in reducing pest populations.

Lure-and-Infect

Lure-and-Infect, also known as auto dissemination, combines an attractive lure with an entomopathogen (such as viruses, bacteria, fungi, or nematodes). Instead of killing the attracted insects, they are inoculated with the pathogen, which they then spread to others, amplifying the treatment and potentially causing widespread disease outbreaks among the pest population. This approach has been successfully explored with various pathogens, including NPV (Nuclear Polyhedrosis Virus) for tobacco budworm, GV (Granulosis Virus) for codling moth, protozoans for *Trogoderma glabrum*, and fungi for pests like the diamondback moth, Japanese beetle, and termites.

Mating disruption

Mating disruption is a pest control strategy that uses species-specific sex pheromones to interfere with mating behavior. By releasing large amounts of synthetic pheromones into the environment, this tactic disrupts male mating attempts. There are four main mechanisms:

Competitive Attraction: Males are drawn away from females by false trails.

1. **Confusion**: Saturation of the environment with pheromones causes random flight patterns, preventing males from locating females.
2. **Sensory Desensitization**: Overexposure to pheromones reduces the males' ability to detect females, causing mating failure.
3. **Disguise**: Excess pheromones cause males to leave the area, making them unavailable for mating.

Mating disruption has been effectively used against lepidopteran pests like orchard moths and the spruce budworm, and for controlling bark and ambrosia beetles using antiaggregation pheromones. This strategy has also been applied to control pests through the use of heterospecific synomones, which disrupt insect aggregation or misdirect insects to already-occupied resources.

Conclusion

semiochemicals hold significant potential for insect pest suppression through various management strategies, including monitoring, mating disruption, mass trapping, and attract-and-kill methods. While monitoring is an effective tool for deciding on control measures, the use of pheromones for mating disruption and pest attraction has shown promise. Despite progress in understanding their practical applications, semiochemicals are not yet widely used in pest management. To fully harness their potential, further research is needed to clarify the origin of these chemical cues and their interactions with insects, hosts, and natural enemies. Advances in molecular and biochemical techniques will be crucial for developing novel, sustainable pest control strategies, and more efficient application technologies are required for widespread adoption.

References

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