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Role of semiochemicals in integrated pest management

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Abstract

Semiochemicals are chemical markers or signals that relay communication is the act of the same or different species (pheromones) (allelochemicals). Kairomones (beneficial to the receiver), synomones (beneficial to both the emitter and the receiver), allomones (beneficial to the emitter), and apneumones (beneficial to the emitter) are examples of allelochemicals (non biological origin). Pheromones for a wide range of insects from different orders have been described, synthesized, formulated, and tested in the field. Several insect species have been monitored for the purposes of population prediction, quarantine screening, and dispersal. For efficient management of insect pests, mass trapping and mating destruction have been used effectively, either alone or in conjunction with insecticides or biocontrol technologies. Indirectly, these approaches limit insecticide use and aid natural enemy survival. Popular Para pheromones used for tracking, mass trapping, and male annihilation include methyl eugenol, cue lure, and Tri Med lure. Plant volatiles are used to mass trap a variety of insects, especially coleopteran pests, either alone or in blends. Besides lepidopteron, coleopteran, and dipteran insects, pheromones have been used for monitoring purposes by insects from other orders, including Homoptera (mealybugs). Natural enemies' success is improved by kairomones and synomones. Insect pest control techniques such as anti-aggregation pheromones and "auto confusion" approaches are relatively new. To make the use of semiochemicals in pest control easier, researchers propose developing low-cost mating disturbance dispensers, semiochemical-based e-noses for tracking, and raising farmer understanding.

Keywords: semiochemicals, pheromones, mating disruption, kairomones, attractant, repellent

Introduction

The term semiochemical is derived from the Greek word "Semeon" which means sign or signal. Insects use semiochemicals to locate mate, host, or food source, avoid competition, escape natural enemies, and overcome their hosts' natural defense systems. Semiochemicals have the advantage of being used to communicate messages over relatively long distances compared with other insect means of communication such as touch. Semiochemicals are chemicals that are used to transport data within living organisms and induce changes in their behavior (Dicke and Sabelis, 1988; Nordlund and Lewis, 1976) [13, 33]. They are released by one organism and cause a reaction in another. Most invertebrates rely on scent as the key sensory modality for detecting their external environment, (Krieger and Breer, 1999) [26]. Insect attraction to plants and other host species requires the identification of specific semiochemicals or specific semiochemical ratios (Bruce *et al.*, 2005a) [9]. The identification of unique semiochemicals or mixtures of semiochemicals associated with non-host taxa requires the avoidance of unsuitable hosts. (Agelopoulos *et al.*, 1999; Bruce and Pickett, 2011; Hardie *et al.*, 1994) [1, 7, 19]. There is a chance to create non-toxic approaches using semiochemicals that affect insect pests' actions for integrated pest control. Attractants can be used to track insect populations in baited traps. Besides, to hold insect populations below threatening levels, semiochemicals that repel pests or attract their natural enemies could be used to maintain insect species under control. Pheromones that act within the same species and allelochemicals, which act between the species, are two different types of semiochemicals. Pheromones originated for contact purposes that provide sex, warning, grouping, and territory marking signals. Allelochemicals are classified as signals that support either the receiver (kairomones), the emitter (allomones), or both (allomones) (synomones) (Nordlund *et al.*, 1981). Semiochemicals may play a variety of roles at various trophic stages, serving a variety of functions. For example, Plant-feeding insects are frequently repelled by herbivore-induced volatiles, whereas their natural enemies are attracted. Since the same chemical compound may have several roles, this terminology is very restrictive. A pheromone that often serves as a kairomone for another species, Dicke and Sabelis (1988) [13] leading to the coinage of the term' info chemical,' which can be especially useful in circumstances involving tri-trophic interactions. Insects are under a lot of pressure to highly interrelated means of detecting nutrition because their life and reproduction are dependent on it. And generalist insects have defenses that prevent them from landing on non-host species.

Semiochemicals are species-specific and harmless to the environment. Semiochemicals are promising tools for the management of agricultural pests, particularly in organic cropping systems, due to their advantages over traditional insect pest control agents. There is an environmental justification for reducing the use of toxic insecticides for pest management, as well as a public concern. Since semiochemicals are largely non-toxic to vertebrates and beneficial insects, are used in limited quantities, and are mostly species-specific, they have a lot of potentials to offer alternate solutions. This review describes using a few examples, below are some of the ways that semiochemicals have been used in integrated pest management (IPM) so far. Limitations on their use are often discussed, as well as potential future solutions.

Pests are the major threat in crop production systems; they limit the vigour and productivity of the crops. To overcome this problem the chemical pesticides were considered to be the most efficient and reliable over several decades. The adverse effect of pesticides on soil, water, humans, animals and ultimately the environment diverted the attention of the scientific community to develop an ecofriendly approach for managing the devastating crop pests (Manda *et al.*, 2020) [27]. Semiochemicals can use in integrated pest management (IPM).

Classification of Semiochemicals

Semiochemicals are classified based on their effect or function which should be considered because the same molecule can act as a pheromone for one insect species while also acting as a kairomone or allomone for another. Semiochemicals are classified into two types: pheromones, which mediate interactions between members of the same species (intraspecific reactions), and allelochemicals, which mediate interactions between members of different species (interspecific interactions). Pheromones are further classified based on their behavioral response into primer pheromones, which cause long-term physiological changes, and releaser pheromones, which cause short-term or immediate behavioral changes. Allelochemicals are classified as kairomones, which mediate interactions in favor of the recipient, and allomones, which favor the emitter. Synomones, which benefit both the emitter and the recipient, and apneumones, which are substances produced by nonliving material that elicit behavioural responses that benefit the receiving organism but are harmful to a second organism found on the nonliving material.

Insect Pheromones

The term pheromone was coined by Karlson and Lüscher to describe chemical signals that mediate intraspecific interactions. Silk worm’s (*Bombyx mori*) sex pheromone was the first to be chemically identified in 1959 and is regarded as the most important semiochemical used in pest management.

Insect parasitoid kairomones

Semiochemicals are important in the host-parasitoid relationship, which Rutledge 1996 classified into three stages: habitat-location, host-location and host-acceptance, and oviposition. Aldehydes, alcohols, sulfur-containing compounds, esters, terpenes, alkanes, heterocyclic aromatic compounds, proteins, amino acids, triglycerides, and salts were among the semiochemicals. Semiochemicals identified in the habitat-location step were most likely from the host insect's host plant, whereas semiochemicals identified in the host-location, host-acceptance, and oviposition steps were mostly from the host insect. Kairomones used by parasitoids to locate their hosts can be divided into two groups, external to the host and Internal Kairomones. External to the host kairomones are long-chain hydrocarbons, ketones of fatty acids, esterified cholesterols, or proteins found in either host frass or glue used to attach eggs to a substrate. Internal to the host kairomones are short-chain hydrocarbons, ketones of fatty acids, esterified cholesterols, or proteins found in either host frass or glue used to attach eggs to a substrate. Internal kairomones are amino acids and salts in the hemolymph that are normally sensed by ovipositors and serve as indicators of the host's suitability for parasitoid offspring, a type of maternity care found in many insect species.

Semiochemicals for Monitoring Pest Populations

One of the most common and successful practical applications of semiochemicals is in pest detection and monitoring (Witzgall *et al.*, 2010) [43]. Monitoring systems are used to time treatments so that they are only applied when economic thresholds are exceeded in order to rationalize pesticide use. Crop scouting by direct inspection of crops is often time consuming and impractical for large-scale agriculture. Semiochemically baited insect monitoring traps may be able to solve this problem.Sex pheromones are useful for this because they are highly attractive and species-specific, though they usually only attract males. The pea moth, *Cydia nigricana*, was the subject of one of the first pheromone monitoring traps (Wall *et al.*, 1987) [41].

Pheromone lures are currently used in traps to monitor a variety of crop pest species (Witzgall *et al.*, 2010) [43]. Such monitoring systems enable farmers to time insecticide applications, lowering both economic and environmental costs. Insecticide sprays that are poorly targeted and unnecessary can have a negative impact on natural pest enemies.The authors recently developed a pheromone trap-based monitoring system for the orange wheat blossom midge (OWBM), *Sitodiplosis mosellana*, at Rothamsted (Bruce *et al.*, 2007) [6]. OWBM is a common and growing pest of wheat in the Northern Hemisphere, causing severe yield losses in high infestation years. Larval feeding on developing seeds causes shriveling and premature sprouting, as well as facilitating secondary fungal attack by *Fusarium graminearum* and *Septoria nodorum*. This has an impact on both the yield and the quality of the harvested grain. Due to difficulties in detecting OWBM prior to the development of pheromone traps, the true extent of crop damage was frequently underestimated. However, in a 2004 outbreak in the United Kingdom, crop losses were estimated to be 6% (1 million tonnes) nationwide, compounded by grain quality reductions, despite insecticide application to approximately 5, 00,000 ha of wheat. The spatial distribution of OWBM is very patchy and varies from year to year depending on climatic conditions. Precipitation causing moist soil conditions at the end of May, followed by warm still weather in late May/early June, can lead to severe OWBM outbreaks in the United Kingdom. The ovipositing female is a small insect that can hide in the crop canopy. The larvae are also hidden within the wheat ear, which is both a cryptic and difficult spray target. To achieve effective control, any insecticide application must be made as soon as possible before larvae burrow in between the lemma and palea. OWBM's female sex pheromone has been identified as (2S, 7S)-non anediyl dibutyrate (Gries *et al.*, 2000) [17]. The authors synthesized the pheromone at Rothamsted and tested different formulations of the pheromone in a series of field trials, with different release profiles, and effective trap and dispenser designs were determined.

Observations of trap catch variability and its relationship to subsequent infestations were used to develop a decision support model (Bruce and Smart, 2009) [8]. This model is a distillation of some complicated data gathered over several years of research, but it has been framed in terms of what it means for farmers who use traps.

Interaction of insects and plants semiochemicals

Insects live in a volatile compound environment that contains insect herbivore, host plant, and insect carnivore semiochemicals. These volatile chemicals interact with one another, eventually changing the behaviour and physiology of insect pest species. Some insects use host plant compounds as sex pheromones or sex pheromone precursors (Reddy, 2004) [36]. Many butterflies, moths, beetles, grasshoppers, and aphids used pyrrolizidine alkaloids derived from their host plants as effective feeding deterrents against natural enemies or predators (Nisidha, 2002).The oil palm *Elaeis guineensis*, the host plant of the African palm weevil *Rhynchophorus phoenicis*, has been shown to produce a mixture of volatile esters, one of which, ethyl acetate, induces male weevils to release the aggregation pheromone E-6-methyl-2-hepten-4-ol or rhyncophorol (Jaffe k *et al.*, 1993). Orchid bee males collect terpenoids from orchids and use them as aggregation pheromones to induce the formation of leks, or sites where males compete for females (Dressler, 1982) [14].

Potential use of semiochemicals in insect pest management

Semiochemicals have been used to control insect pests for over a century (Soroker *et al.*, 2015) [39]. Insect sex pheromones are semiochemicals that are widely used in the management of insect pests, particularly those belonging to the order Lepidoptera. Aggregation pheromones from the order Coleoptera are also used to control economically important agricultural insect pests.Semiochemicals have successfully managed several serious agricultural pests, including the carob moth *Ectomyelois ceratoniae*, the fall armyworm *Spodoptera frugiperda*, the tomato leaf miner *Tuta absoluta*, fruit flies *Bactrocera sp*., mountain pine beetle (MPB) *Dendroctonus ponderosae*, Asian citrus psyllid *Diaphorina citri*, and the red palm weevil (RPW). Semiochemicals are considered safe and environmentally friendly molecules due to their natural origin, low persistence in the environment, and species specificity, all of which contribute significantly to their non-target organism toxicity (Horowitz, 2009).

Semiochemicals are utilized for the management of insect pests through the following tactics:

1. Detection of invasive species and in delimiting surveys.
2. Monitoring the populations of endemic species to synchronized the timing of insecticide treatments
3. Evaluationoftheeffectivenessofpestmanagementtacticsthroughpost-applicationassessment.
4. Improvement of old method of insect counts used for decision-making.
5. Increasingtheeffectivenessofbiologicalcontrolbyincreasingthepredation/parasitismratesofpredators and parasitoids.
6. Reduction of pest population through mating disruption, attract and kill, mass trapping and repellency techniques.
7. Strategy for use of the semiochemicals in the Pest Suppression.

The most successful approach to using Semiochemicals in pest control is to monitor pest population activity or to determine the number of an insect population in order to take the necessary need-based control measures. A large number of synthetic pheromones are released into the crop to prevent or delay mating, thereby reducing the likelihood of an insect in the next generation. Mass trapping is thought to be the most effective method for suppressing and eradicating low density and isolated pest populations. The main goal of mass trapping is to catch the insect in order to remove a large number of insect populations from a source before mating, oviposition, or feeding, thereby preventing crop damage.

Semiochemical-based pest control techniques

Attract and kill (A&K)

The technique uses an attractant or semiochemical to lure an insect to a point source containing a killing agent (insecticide, pathogen, or sterilant), as the name implies; thus, the techniques are referred to as attract and kill, attract and infect, and attract and sterilize, respectively. The technique reduces the insect population by killing the target insect, reducing its fitness and fecundity, or disabling it by infecting it with disease.

Semiochemicals have a successful practical application in monitoring the presence and abundance of pest populations (Witzgall *et al.*, 2010) [43]. The monitoring system aids in the decision-making process for pest control measures that keep the pest population below the economic threshold level. It can be done using either kairomones or pheromone baits or traps. Tarps based on kairomones have been widely used to monitor the biological control agent *Rhizophagus grandis*, a predator of the spruce bark beetle *Dendroctonus micans* population (Hosking *et al.*, 2003) [21]. Because of the strong attractant and species specific nature of pheromone attraction, pheromone bait traps are more effective in monitoring insects than kairomones (El-Sayed *et al.*, 2006) [16]. A pheromone-based monitoring system can be used to assess population abundance and trends, as well as the damage caused by insect pests. Thresholds of the catch are determined based on the magnitude of trap captures, either for timing or deciding whether or not to take control measures (Meurisse *et al.*, 2008) [30]. Pheromone lures are currently used in traps to monitor a variety of crop pest species. These pheromone traps are used to detect low-density populations as well as to monitor the presence of invasive species and to prevent their establishment and spread (Trematerra, 2012) [40]. Multiple pheromones in a single trap are a new trapping system for monitoring the behaviour of different species in the stored grain pest. Sex pheromones for *Ephestia cautella* (Walker), *E. kuehniella*, *Plodia interpunctella*, *Trogoderma granarium* (Everts), and aggregation pheromones for *Tribolium castaneum* and *Tribolium confusum* are mixed into natural food attractant oils for trapping.

Mating Disruption

The method is most commonly used in semiochemical pest control. It manipulates insect behaviour in such a way that population numbers are reduced. The environment where a specific insect pest needs to be controlled is saturated with synthetic sex pheromones, interfering with males' ability to locate the natural pheromone plume emitted by females. Mating disruption with synthetic pheromones or para pheromones does not completely stop mating, but it does reduce female fecundity by approximately 50%. Insect females have a limited time to mate and reproduce, and any delay in mating may affect their fitness and ability to select suitable oviposition sites (Rochat *et al.,* 1991) [37]. Some insects' mating systems involve the transfer of specific peptides that cause the females to lay eggs. Four mechanisms have been proposed to explain how mating disruption occurs:

Competitive attraction or false trail following

This happens when males respond to synthetic pheromone plumes produced by semiochemical dispenser rather than the natural plume emitted by the calling female (Rochat *et al.,* 1991) [37]. This mechanism is density-dependent and decrease in efficiency population of pest increases.

Camouflage

This mechanism requires complete saturation of the environment with the synthetic pheromone. In this case, the male cannot locate the positions of the females and it is density-independent.

Sensory Imbalance

Adaptation of the male olfactory receptor system or habituation of the central nervous system may occur due to the overexposure to synthetic pheromone.

Mating Disruption Strategy

Mating disruption is a technique in which synthetic sex pheromones are dispensed into the pest habitat in sufficient quantities to reduce a male's ability to locate the female, thereby affecting the organism's ability to reproduce (Mauchline *et al.,* 2018) [28]. Attractant insect pheromones, such as sex and aggregation pheromones, are species-specific Semiochemicals signals that have been identified and successfully used in many insect pest management programmes worldwide (Gut *et al.,* 2004) [18]. Mating disruption using sex pheromones has been successfully implemented in pest management programmes for many pest species, particularly Lepidoptera pests of fruits, vegetables, and forests (Welter *et al.,* 2005 and Cork, 1996) [42, 11]. Control of the codling moth, Cydia pomonella in pome fruit, the oriental fruit moth, *Grapholita molesta* in stone fruit like peaches and nectarines, the tomato pinworm, *Keiferia lycopersicella* in vegetables, the pink bollworm, *Pectinophora gossypiella* in cotton, and the omnivorous leafroller *Platynota stultana* in vine yards have been reported. Mating disruption was found to be effective in India using a blend of Z-9-hexadecenal, Z-11-hexadecenal, and Z-9-octadecenal in a polyvinyl chloride (PVC) resin formulation (El-Sayed *et al.,* 2006) [16]. A pheromone blend of Z-1- octadecenal and Z-13- octadecenol is used to control the sugarcane borer, *C. sacchariphagus indicus* (Rochat *et al.,* 1991) [37].

Mass Trapping

It's a pheromone technique that's commonly used for direct insect population control. The technique is defined as the placement of a sufficient number of pheromone traps in a dense enough density to eliminate enough adults from the population and thus reduce subsequent larval damage (Baker, 2011). Pheromones for monitoring are typically used at low densities, and trapped insects have no effect on population reduction (Baker, 2008) [2]. In the case of male-emitted pheromone systems that attract females, such as weevils (red palm weevil) and snout beetles, mass trapping is effective. Females are trapped in this system, so mass trapping directly reduces egg laying. The technique works well with insects that have a low population density, live a long time before egg-laying, lay a small number of eggs, and the emerging larvae cause significant damage (Oehlschlager, 2002) [34].

Attractant

The attract and kill technique involves the use of semiochemicals to lure an insect to a source containing a killing agent, which results in the reduction of the insect population by killing or reducing the fitness of the target insect. Plants have evolved a plethora of defence mechanisms against insect attack, including the release of defence volatiles. These volatiles aid in plant defence by repelling phytophagous insects directly and/or indirectly by attracting natural enemies antagonistic to herbivores (Khan *et al.,* 2010). Pheromones (e.g., sex pheromones), kairomones (e.g., host volatiles), attractants with a known behavioral function (e.g., host plant or oviposition odors), and attractants identified through the screening of candidate chemicals with poorly known behavioural functions are examples of semiochemicals used in attract and kill. Appropriate plants that naturally emit signaling chemicals Semiochemicals were discovered (El- Sayed, 2009) [15]. The use of lure and kill for pest management of pink bollworm, Egyptian cotton leafworm, codling moth, apple maggot, biting flies, and bark beetles, as well as the eradication of invasive species such as tephritid fruit flies and boll weevils, has been reported (Mensah, 1996).

Repellent

A repellent is a substance that prevents insects from finding, feeding, or ovipositing on the host. In pest control, repellent is used to create an odor barrier to prevent an arthropod from entering a space occupied by a potential host, acting as a "safe zone" to reduce insect-host encounters (Cook *et al.,* 2007). Semiochemicals with repellent properties are used to control agriculturally important pests. Citronella oil and pine oil, for example, have been found to have repellent or oviposition deterrent properties against some insects. DEET is widely regarded as the most effective commercial repellent on the market, and it is primarily used to repel hematophagous insects.

Petroleum spray oils on cotton may have a deterrent effect, suppressing *Helicoverpa spp.* oviposition on these plants (Battacharya, 2017). Pentadecanal, an allelochemical, has been shown to be an oviposition deterrent against the stem borer, *Chilo suppressalis*.

Push Pull Strategy

Push-pull is a pest control strategy that employs repellent and attractant Semiochemicals to manipulate pests and their natural enemies (Pickett *et al.,* 2014) [35]. The push pull strategy for pest suppression is a new pest control method that uses non-toxic components to reduce pest population while using less pesticide (Agelopoulos *et al.*, 1999) [1]. The Push-pull strategy employs Semiochemicals for behavioural manipulation of insect pests and their natural enemies by integrating insect stimuli that make the protected resource unpalatable and unattractive to the pests (push component) while luring them towards a more appealing source (pull component) where the pests can be removed. The push component is a trap crop or intercrop grown around the perimeter of the main crop. Cues that reduce pest colonization and development protect the main crop, resulting in a push effect (Khan *et al.*, 2007) [24]. These cues are semiochemicals, specifically kairomones, which repel pests and drive them away from the primary crop (Midega *et al.*, 2018) [31]. It was reported that the Napier grass was planted as a border and intercrop alongside the main crop to control stem borer infestation (Bright well *et al.*, 1991) [5]. The volatile that acts as an oviposition attractant for the gravid stem borer adult female is secreted by Napier grass. The push-pull system was tested in the management of the fall armyworm, *Spodoptera frugiperda*, in maize crops. Maize crops are protected by semiochemicals emitted by the intercrop, *Desmodium intortum*, which repel stem borer moths while cues emitted by the border crop, *Brachiaria*, pull them.

Lure and Kill

The most common examples of mass trapping combined with insecticides are found in lure and kill or attracticide technology (Jones, 1998) [23]. Lure and kill approaches, which use specific formulations of attractants and insecticides, have been used in pest management for several decades, and many case studies have been thoroughly reviewed by (El-Sayed *et al.*, 2009) [15]. The pest is drawn to the semiochemical lure, but instead of being trapped, it is killed by a toxicant, which is typically an insecticide but can also be an insect pathogen (lure and infect).Pest population reduction by lure and kill is less expensive than mating disruption because smaller amounts of pheromone are required and the insecticide component is limited to very small areas, reducing crop contamination and thus being more environmentally friendly.

Conclusion

Semiochemicals have the potential to play a role in insect pest suppression through a variety of management strategies. Monitoring and detection, mating disruption, mass trapping, and attract and kill repellent techniques are among them. Monitoring is regarded as an effective tool for deciding on a control measure. The use of pheromones to disrupt mating is a successful pest control strategy. Recently, the most common application of Semiochemicals has been to attract, trap, and kill insect pests. Many research findings on the practical use of Semiochemicals for monitoring and pest suppression have been discovered, but they are not yet widely used. To understand the role of Semiochemicals in pest suppression, we should be able to clarify the origin of these chemical cues in addition to studying the behavior interaction of host-insect-natural enemies. New locations for the production of the behavior-modifying chemical signal will reveal the specific target and disrupt the insect-behavior. Pest's To develop similar novel and sustainable insect pest management strategies, a thorough understanding of the biochemical, molecular, and behavioral ecology of plant insect interactions is required. Recent advances in molecular access will pave the way for further research into the role of semiochemicals in pest control applications in the future. There is a need for more efficient technology methods for the application of semiochemical-based control methods.

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