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Insect Behaviour Modulation Using Pheromones

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Insects represent the most diverse and ecologically successful group of organisms on Earth. Their dominance is largely driven by complex communication systems, with chemical signaling particularly through pheromones playing a central role in coordinating social and survival behaviors (Adetunji *et al*., 2023). Pheromones are chemical signals used for communication between members of the same species. Some of the most important decisions made by organism are mediated by pheromones. Many of these signals, particularly those produced by insects, are lipid molecules. Among the numerous roles that have been elucidated for pheromones include attraction, aggregation, aphrodisiacs, anti-aphrodisiacs, kin-recognition and alarm signaling. So pervasive are these molecules that a number of organisms mimic the chemical language of insects in order to lure prey or unwitting pollinators. For example, predatory bolas spiders emit the same sex attractant signals used by moths to ensnare the moths at close range by swinging a bola of silk. Pheromones are defined as species-specific chemical substances secreted externally by an individual, which trigger innate behavioral or physiological responses in other members of the same species. These signals govern a wide spectrum of activities including mate location, aggregation, trail following, alarm signaling, and defense mechanisms. Over the past several decades, scientific exploration into insect pheromones has expanded, aided by developments in analytical chemistry, behavioral ecology, electrophysiology, and molecular biology. (Begum *et al*., 2021). Particularly in agriculture, the discovery, description, and synthetic replication of pheromones have created novel approaches to pest management. Pheromone-based techniques are target-specific, non-toxic, environmentally benign, and frequently compatible with organic and integrated pest management (IPM) strategies, in contrast to conventional insecticides. Pheromone-based control techniques are becoming more and more appealing as environmental contamination, pesticide resistance, and biodiversity loss become major global concerns. By taking use of insects' natural communication channels, methods including mass trapping, lure-and-kill systems, and mating disruption disturb insects' reproductive cycles or divert them from vital crops. Because of their specificity and lower environmental costs, these interventions are not only successful but also frequently long-term economically viable.

Types of Insect Pheromones

Insect pheromones are classified based on their biological function and the type of behavioral or physiological response they elicit in the recipient. Understanding the types of pheromones is crucial for designing effective strategies to manipulate insect behavior for ecological or pest management purposes. Broadly, insect pheromones are categorized into the following types:

Aggregation Pheromones : These pheromones lead to the clustering of individuals, often for feeding, mating, or protection. Unlike sex pheromones, aggregation pheromones are usually produced by both sexes. A well-known example is the red flour beetle (*Tribolium*

castaneum), which emits an aggregation pheromone that attracts conspecifics to a food source. These are exploited in lure-and kill and push-pull systems.

Alarm Pheromones : Alarm pheromones are released in response to predation or disturbance and cause immediate escape or aggressive behavior in conspecifics. They are common in eusocial insects such as ants, bees, and aphids. For example, when attacked, aphids release (E)-β-farnesene, prompting others to flee. These pheromones have been considered for crop protection by triggering avoidance behaviors in pest species.

Trail Pheromones : Trail pheromones are mostly used by termites and ants to indicate routes to new nesting locations or food sources. Foragers continuously deposit these compounds, and other colony members follow suit. Foraging efficiency is influenced by their stability and frequency of renewal. It is possible to control invasive species' migratory habits by using synthetic trail pheromones.

Sex Pheromones : These pheromones, which are important in mating behavior, are among the most researched. Sex pheromones, which are mostly released into the environment by females (although they are also produced by males in certain species), are used to attract mates over great distances. For example, male *Helicoverpa armigera* moths use highly sophisticated olfactory receptors to identify a combination of volatile substances released by females. In pest management, these pheromones are essential for mass capturing and mating disruption tactics.

Mechanisms of Behavioural Modulation

Pheromones are not merely chemical cues they are powerful modulators of insect behavior, capable of eliciting rapid and often stereotyped responses that are critical for survival, reproduction, and social organization. The mechanisms by which insects translate pheromone signals into behavior involve tightly regulated neural and endocrine pathways. This section explores the key behavioral processes influenced by pheromones and the underlying biological systems that mediate these changes (Kaur *et al*., 2024).

Mate Attraction and Courtship Behavior : Sex pheromones are essential for mate location and selection in many insect species. Typically, females release volatile sex pheromones into the environment, which attract conspecific males over long distances. Upon detection, males orient toward the pheromone source using anemotaxis (wind-directed movement). The final stages of courtship often involve close-range contact pheromones, which confirm species identity and readiness to mate.

Aggregation and Group Behavior : Aggregation pheromones induce insects of both sexes and multiple developmental stages to assemble in a particular area. This behavior is common in species such as bark beetles and locusts, where coordinated mass behavior aids in survival, feeding, or reproduction. The release of aggregation pheromones can trigger positive feedback loops, where each new arrival contributes to further release and attraction, resulting in rapid population clustering.

Alarm and Defensive Responses : Alarm pheromones are rapidly released in response to threats and provoke immediate defensive or evasive behaviors in nest-mates or conspecifics. In aphids, the release of alarm pheromones causes others to drop from the plant to escape predation. In social insects like ants and bees, alarm pheromones trigger aggressive defense responses and recruitment of nest mates to the source of disturbance. These pheromones often act within seconds and degrade quickly to prevent prolonged unnecessary activation.

Social Regulation in Eusocial Insects : Pheromones control caste differentiation, reproduction, and task distribution in termite, ant, and bee colonies. Primer pheromones, like the queen mandibular pheromone in honeybees, have physiological effects that last for a long time. For example, they can prevent workers' ovaries from developing. These pheromonal mechanisms ensure the success of intricate eusocial systems by preserving colony homeostasis and reducing intra-colonial conflict. Comprehending these pathways offers the behavioral background required to create pheromone-based therapies tailored to individual species that complement natural communication systems, maximizing effectiveness and reducing ecological disturbance.

Applications in Pest Management

The use of pheromones in pest management has become a cornerstone of environmentally conscious agricultural practices. Unlike conventional insecticides, which often pose risks to human health, non-target organisms, and the environment, pheromone-based strategies offer a highly specific and sustainable alternative. By mimicking natural chemical communication signals, these methods can manipulate pest behavior in a way that disrupts population growth and reduces crop damage without contributing to pesticide resistance or environmental contamination. Pheromones and poisonous substances are combined in the lure-and-kill tactic. According to this method, insects are drawn to a source that contains a biological agent or pesticide in addition to the pheromone. The bug is eliminated upon contact or consumption. By using fewer pesticides and limiting their application to particular sites of action, this method lessens the impact to the environment. In a number of cropping systems, lure-and-kill methods have shown promise in controlling cotton bollworms and fruit flies. In addition to direct suppression techniques, pheromones are essential in pest monitoring and early detection. By using pheromone-baited traps, farmers and pest control agencies can estimate population levels, track seasonal dynamics, and make informed decisions about intervention thresholds. This monitoring enables timely and precise pest management, improving efficiency and minimizing unnecessary pesticide applications (Sharifi and Ryu, 2020). Additionally, pheromones are essential to integrated pest control (IPM) initiatives. Pheromone-based methods improve the overall sustainability and resilience of pest management systems when used in conjunction with biological control agents, cultural practices, and mechanical interventions. Because they are species-specific, they cause the least amount of disturbance to pollinators and natural enemies, maintaining the equilibrium of the ecosystem (Singh *et al*., 2020).

Conclusion

Pheromone-based insect behavior modification is one of the most elegant and environmentally and scientifically sound methods of managing pests. In addition to expanding our knowledge of insect ecology over the past few decades, developments in pheromone chemistry, perception mechanisms, and behavioral outcomes have also led to a number of useful, sustainable applications in public health, forestry, and agriculture. Looking ahead, the integration of pheromone technology with digital tools, microbial biosynthesis platforms, and environmentally adaptive delivery systems is expected to enhance both accessibility and efficacy.

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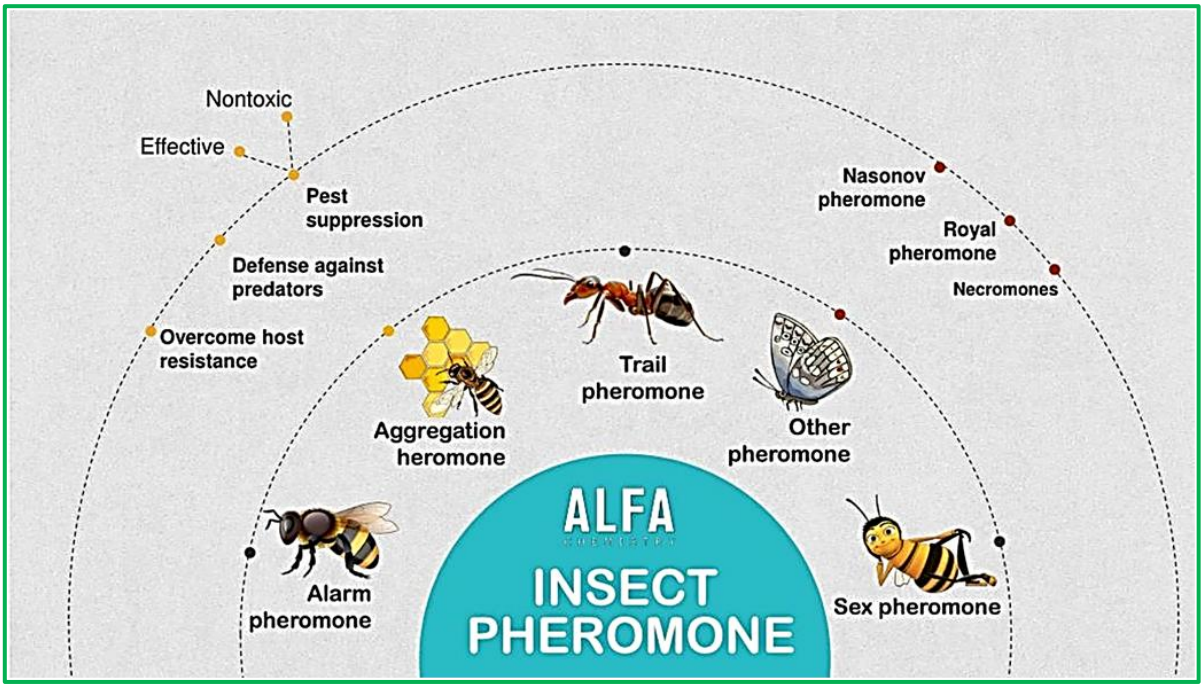
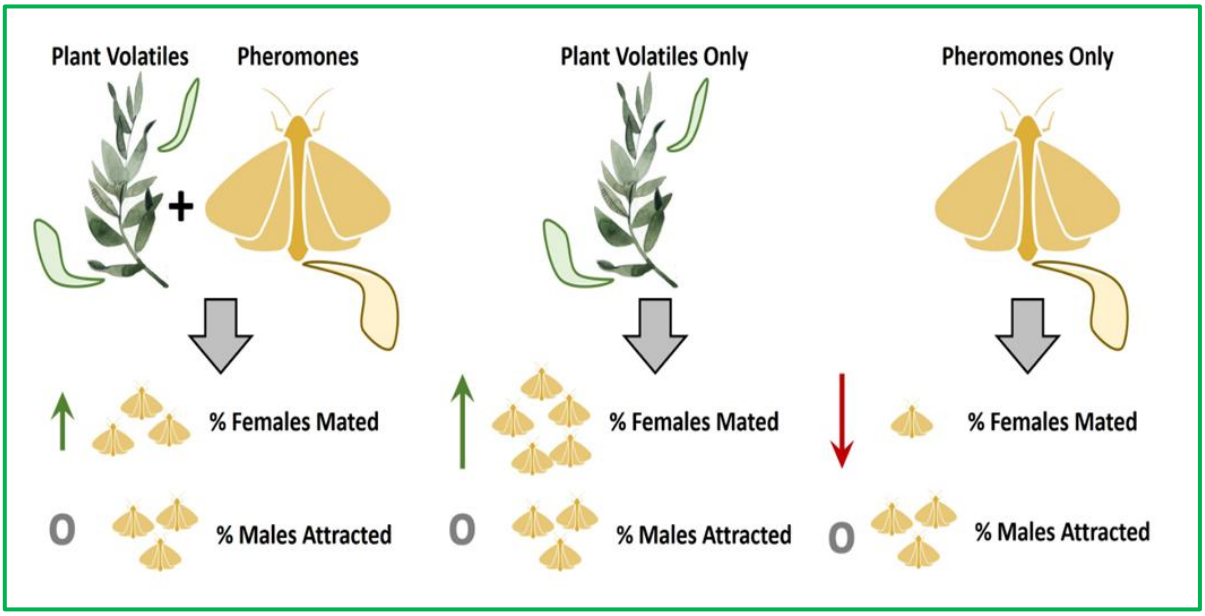

Nontoxic
Effective
Pest suppression
Defense against predators
Overcome host resistance
Nasonov pheromone
Royal pheromone
Necromones
Trail pheromone
Aggregation heromone
Other pheromone
ALFA
INSECT PHEROMONE
Alarm pheromone
Sex pheromone


Plant Volatiles
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