

INSECT PHEROMONE:CLASSIFICATION, STRUCTURE OF PHEROMONE GLAND, BIOSYNTHESIS AND APPLICATION IN PEST MANAGEMENT

Abstract

All living beings communicate with each other by means of physical or chemical cues. Insects are the most diverse group of organisms in the earth. Insects like other living organisms communicate with each other in various occasions such as for habitat marking, for mating, to warn other members of potential threats etc. Among all the communication cues, pheromone that mediates communication via chemical cues is the oldest one seen in insects. Various types of pheromones like sex attractants, alarm pheromone, aggregation pheromone are seen among insect orders. Pheromone, because of its high species specific are utilized as pest management tool in several field crops like rice, cotton etc. as alternative to chemical control in Integrated Pest Management. However, despite of its advantages such as, eco-friendly, cost-effectiveness, requirement in very small amount, non-toxic to non-target organisms, pheromone based pest management is still is less popular in several sectors like tea. This chapter gives a brief overview of the types of pheromones and their synthesis with reference to their utilization in pest management.

Keywords: Pheromone, Lepidoptera, Coleoptera, Integrated pest management

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I. INTRODUCTION

All living organisms communicate with each other and it is crucial for survival, mostly reproduction (1). Communication is the transmission of information (which may be intentional such as courtship display or unintentional such as scents from predators to prey) from one or more senders to one or more receivers that influences the receivers' present or future behavior. Among all the communication modes, olfactory communication is the oldest mode applied by animals. Volatile substances are present in all living things produced as a result of the organism's metabolic activity. Small nutritional, environmental, and genetic variations makes it unlikely that any two creatures will create identical mixture of volatile chemical substances, which is the basis for their species-specific reaction (2). Three modes of communication can be seen in insects viz. Olfactory, acoustic and visual of which olfactory is the predominant one (3). Olfactory response is stimulated by low concentration of volatile substances. Such chemical compounds that are released by an individual having the capacity to modify the perceiver's behavior are termed as semiochemicals (4) which may be either intra-specific (Pheromones) or inter-specific (Allelochemicals). Karlson and Luscher (1959) proposed the term 'pheromone' to describe the species-specific reaction of a chemical secreted by an animal. Since then the term has become subject of active study (5). Pheromone, emitted by living organisms that induces behavioral change in other conspecific individuals (6) are volatile, low molecular weight organic compounds having variable structures (7). The change in behavior can either be quick or immediate (Releaser) or through changes in development such as reproduction, growth (Primer) etc. Pheromones also called olfactory stimulants can be classified based on their biological functions.

II. CLASSIFICATION OF PHEROMONE (Fig.1)

1. **Sex Pheromones** typically released by females to entice males of the same species for mate with exception in some cases where males also release such pheromones e.g., males of *Bicyclus anynana* (8). Lepidopteran sex pheromone is the most studied IPM strategy.
2. **Aggregation Pheromone** released by one sex which can attract both the sexes. In IPM aggregation pheromone has the potential to be used for monitoring and trapping (9).
3. **Alarm Pheromones** released by social animals to warn other members of the group of a threat (2). For example, sesquiterpene (E)-b-farnesene (Ebf) is released by aphids in response to predation (10).
4. **Oviposition Deterring Pheromones** also known as epideictic pheromone reduces intra-specific competition for egg deposition on host (11). For pests to survive, a strong communication viz., habitat marking, searching for mate, anti-predatory response etc are essential means (12). Pheromones (Chemical cue), being the oldest form of communication play vital role in insect communication (12). Chemical cues have advantages as it takes little effort to be made and released and are effective irrespective to light and being long lasting. The most advantageous characteristic is the coded language that is highly specific to the members of the same species and others such as predators cannot decode (13).

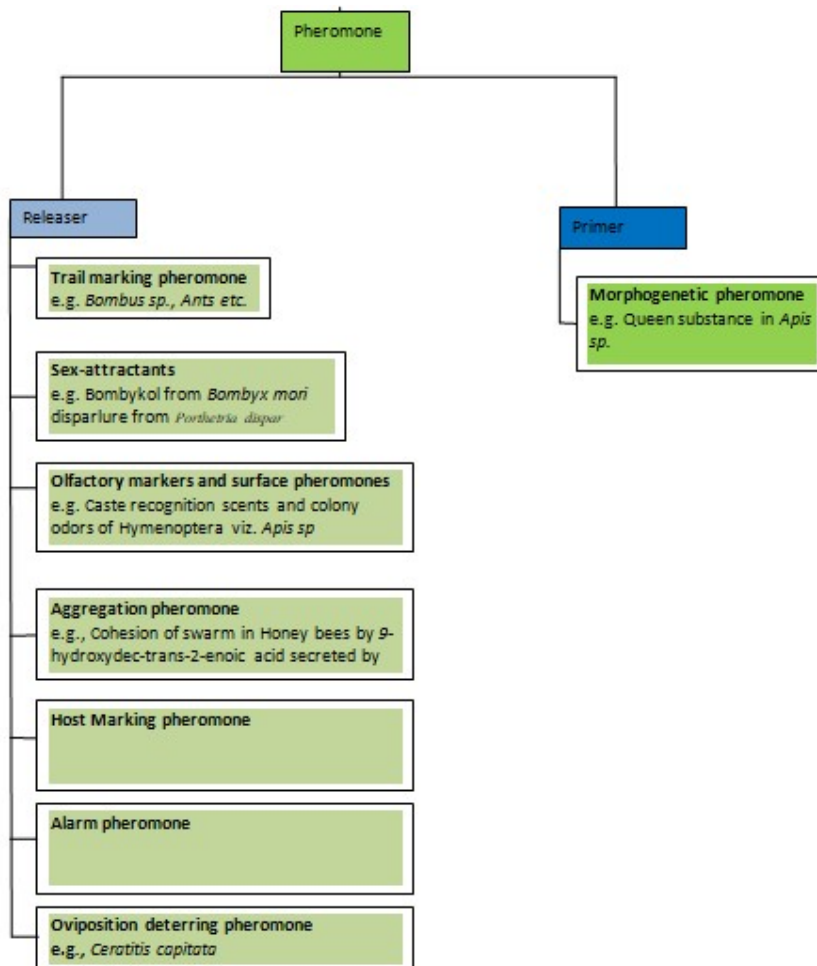


Figure 1: Classification of Pheromone based on their biological function

III. PHEROMONE GLAND

Pheromone producing glands are exocrine glands in general (14). Location and structure of the pheromone gland varies among insect orders. Pheromone producing glands in insect differs in both location and morphology. The cells that are modified for the secretion of pheromone are ectodermal cell (15). It can be a simple unicellular gland distributed over the integument or a complex multi-cellular pheromone producing tissue located on antenna, abdomen, legs and thorax (16). Contrast to the hormone producing glands pheromone producing glands are ductless gland or connected to tubules that leads the pheromone compounds to the exterior (14). Only one type of glandular cells is found to be associated with pheromone secretion in majority of the studies in lepidopteran pheromone gland (17). Exception was found in the study of Hallberg and Subchev (1996) in *Theresimima ampelophaga* with two cell types in pheromone gland viz. gland cells and wrapping cells (18). Conner et.al 1980 identified some intriguing characteristics of the sex pheromone gland of the Arctiid Moth (*Utetheisa ornatrix*). He proposed the gland to be covered with only glandular epithelium and to be partially compressible due to presence of spiny projections

internally(19). Such cuticular projections found in pheromone glands can be eversible or non-eversible which prevents extra evaporation of pheromone by retracting the gland and by preventing collapse of the gland (16).

Table 1: Location of pheromone gland in different insect orders.

Sl No	Insect species	Pheromone type	Order	Gender	Location of the gland	Reference
1.	Aphids	Alarm	Hemiptera	---	Cornicles	(20)
2.	<i>Ips paraconfusus</i>	Aggregation	Coleoptera		midgut	(21)
3.	<i>Bombyx mori</i>	Sex attractant	Lepidoptera	Female	Lateral glands of last abdominal segments	(5)
4.	<i>Tenebrio molitor</i>	Sex attractant	Coleoptera	Male and Female	Last abdominal segment	(5)
5.	<i>Spodoptera frugiperda</i>	Sex attractant	Lepidoptera	Female	Last abdominal segment	(22)
6.	<i>Pissodes nemorensis</i>	Aggregation	Coleoptera	Male	Hindgut	(7)
7.	<i>Solenopsis invicta</i>	Alarm	Hymenoptera	Female	Mandibles	(23)
8.	<i>Ceratitidis capitata</i>	Sex attractant	Diptera	Male	7 th abdominal segment	(24)
9.	<i>Batrissus sp.</i>	Sex Pheromone	Coleoptera	Male	Apical antennal segment	(25)
10.	<i>Poeciloceris pictus</i>	Sex Pheromone	Orthoptera	Female	Between metathorax and 1 st abdominal segment	(26)
11.	<i>Semiothisa eleonora,</i>	Sex pheromone	Lepidoptera	Male	Femur and tibia of the hind leg	(16)
12.	<i>Thrips validus,</i>	Attractant and aphrodisiac	Thysanoptera	Male	Abdominal segment	(27)

					III-VIII	
13.	<i>Hodotermes mossambicus</i>	Sex attractant	Isoptera	Male	Sternal gland	(28)
14.	<i>Apis mellifera</i>	Queen pheromone	Hymenoptera	Female	Mandibular gland	(29)

Table2: Structure of the pheromone gland in coleoptera and Lepidoptera.

Insect Species	Order	Structure of the Cuticular surface of the gland	Reference
<i>Diabrotica virgifera</i>	Coleoptera	Polygonal with tubercles	(30)
<i>Samia cynthia ricini</i> ,	Lepidoptera	Irregular mammiform protuberances	(31)
<i>Dermestes maculatus</i>	Coleoptera	Semiglobular glands with secretory cells connected to tubuli leading to cribellum.	(14)
<i>Lasioderma serricornis</i>	Coleoptera	Lobate gland connected to tubuli and leads to apodeme.	(14)

IV. PHEROMONE BIOSYNTHESIS

One component pheromones are uncommon and most are blends of multiple components. Precursors for pheromone biosynthesis can be derived from dietary intake. Hughes (1974) studied monoterpeneoid myrcene as a precursor of Aggregation pheromone in *Ips* beetles which showed that only after exposure to myrcene males produced pheromone. Pheromone biosynthesis in bark beetles were found to be derivatives of their host plant precursors. For example, active components identified in *Ips confusus* pheromone viz. ipsenol, ipsdienol, and cis-verbenol were derivatives of plant monoterpenes (32). Although many studies earlier supported this model, however later studies were carried to challenge this model. Biochemical studies showed de novo synthesis of ipsenol, ipsdienol and amitinol by incorporating (1-14C) acetate by bark beetles *Ips paraconfusus* and *Ips pini* (33). De novo synthesis of Frontalin by mevalonate pathway was reported in *Dendroctonus* spp. (34).

Since Bjostad and Roelofs first described the moth sex pheromone biosynthetic pathway in 1983, a number of additional biosynthetic pathways have been discovered as modifications of fatty acid biosynthesis (35). The moth pheromones can be identified into type I, Type II and Type III based on their hydrocarbon chain structures. Type I pheromones typically consists of short unsaturated hydrocarbon chain with oxygenated functional group (Alcohol or aldehyde) linked by ester linkage (36). The type II pheromone consists of hydrocarbon chain with multiple double bonds and ether derivatives. Type III pheromones are structurally similar to Type II but with one or more methyl branches. Approximately majority (75%) of all identified moth pheromone belong to the Type I pheromone (37). Fatty acid research techniques along with Gas chromatography coupled with Mass spectroscopy

have been utilized in identification of the biosynthetic pathway (35). Different enzymes are involved in a array of enzymatic reactions which follows desaturation reaction by Fatty Acid Desaturase (FAD), Reduction reaction by Fatty Acid Reductase, Chain shortening and chain elongation. Heliothine moths, *Helicoverpa* and *Heliothis* produces Z11-16:Ald as major sex pheromone component. The biosynthesis steps follow desaturation of 16:C₀A to Z11-16: C₀A by Δ 11 desaturase. Z11-16: C₀A is then converted into aldehyde Z11-16:Ald (38).

Table 3: Blends of components identified in pheromone of some economically important Insect species.

Insect name	Order	Family	Identified compounds	Reference
<i>Busseola fusca</i>	Lepidoptera	Noctuidae	(Z)-11-tetradecen-1-yl acetate (Z11-14: Ac), (E)-11-tetradecen-1-yl acetate (E11-14: Ac), and (Z)-9-tetradecen-1-yl acetate (Z9-14: Ac), (Z)-11-hexadecen-1-yl acetate	(30) (40)
<i>Lymantria dispar</i>	Lepidoptera	Erebidae	2-methyl-7R,8S-epoxy-octadecane	(41)
<i>Ips confusus</i>	Coleoptera	Curculionidae	Ipsenol (2-methyl-6-methylene-7-octen-4-ol), ipsdienol (2-methyl-6-methylene-2,7-octadien-4-ol, and cis-verbenol	(32)
<i>Bombyx mori</i>	Lepidoptera	Bombycidae	E10, Z12-hexadecadien-1ol	(35)
<i>Scirpophaga incertulas</i>	Lepidoptera	Crambidae	Z9-16:Ald Z11-16:Ald	(42)
<i>Helicoverpa armigera</i>	Lepidoptera	Noctuidae	Z11-16:Ald Z9-16:Ald Z7-16:Ald	(43)
<i>Scirpophaga excerptalis</i>	Lepidoptera	Crambidae	Z11-16:Ald E11-16:Ald	(43)

<i>Spodoptera exigua</i>	Lepidoptera	Noctuidae	(Z,E)-9,12-tetradecadienyl acetate, (Z)-9-tetradecenyl acetate, (Z)-11-hexadecenyl acetate, (Z,E)-9,12-tetradecadienol, (Z)-9-tetradecenol, (Z)-11-hexadecenol	(44)
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V. PHEROMONE IN PEST MANAGEMENT

In the western countries, agricultural, forestry, and public health sectors all use semiochemical-based pest management technology to track and manage insect pests. Insect pheromones are most frequently used to monitor pest populations, which affects millions of acres of agricultural crops globally (45). An estimated of tens of millions of lures are produced annually for mass trapping and monitoring, covering at least 10 million hectares. Pheromone based control of Rice stem borer *Scirpophaga incertulas* has been adopted in Bangladesh after recognizing the limitations of pesticide used (46). There are many registered commercially available pheromones for pest control. There is no evidence that any of the numerous pheromones used for pest control have a negative impact on the environment, non-target organisms, or public health. Lepidopteran pheromone residues in pheromone-treated food crops have not been found because pheromones are applied in slow release formulations, resulting in low exposure (47). Advantage of pheromone based pest management over insecticides is that pheromone produces long term pest control which is not seen in case of insecticides (48). Also, overuse of insecticides leads to secondary pest outbreak due to elimination of their natural predators. Pheromone by nature is highly species-specific targets only the target species. Even incomplete blends can also discriminate between target and non-target species (49).

1. Detection and Monitoring: Sex pheromones are used in detection and population monitoring, two of their most popular and effective applications. A specific insect's presence and the beginning of its seasonal flight period can be determined by capturing it in traps that have been baited with artificial pheromone lures. (47). Size of trap captures is used to determine threshold at which control is needed or decision is to be made on control measures. Pheromone traps are useful for tracking invasive species during the establishment phase because they are sensitive enough to detect low-density populations (50, 51). Several factors are to be considered while applying pheromone trap. Since release rates and chemical impurities, even in trace amounts, have a significant impact on a lure's attractiveness, the attractant and dispenser material must be subject to strict quality control. Other parameters such as attractant, dispenser, location and trap design should be kept constant throughout the procedure (52). A sound knowledge of pest

biology and their geographical distribution is important for establishing an effective pheromone trap (47).

2. **Mass Trapping and Attract and Kill:** Pheromones can be used to control insect populations primarily through two methods: mass annihilation and disruption of mating. Female fertilization is delayed, reduced, or prevented by mating disruption. Mass annihilation relies on attract and kill by using lures in combination with insecticide treatment (47). Since males can mate with more than once in their lifetime, therefore reduction in the male population is essential to control a pest population which has been shown in many mating disruption studies (53, 54, 55). To lower the population density of the target species and/or minimise pest damage, mass trapping is a direct control method that employs a significant number of pheromone traps and is more efficient than mating disruption (55; 56, 57). In case of aggregation pheromone, mass trapping is more effective than sex pheromone as aggregation pheromone can attract both the sexes whereas sex pheromones only attracts the opposite sex (57). Mass trapping has been deployed against many pests of cotton, palm weevil, bark beetles, corn rootworms as well as some invasive species like *Anthonomus grandis* (58; 59). Examples of mass trapping using pheromone baited trap include trapping of tomato leaf miner *Tuta absoluta* using homemade traps with 0.5gm of pheromone (60), *Cosmopolites sordidus* and *Metamasius hemipterus* with sugarcane-pheromone baited traps in banana plots etc (61).

VI. CONCLUSION

Traditional pest control method relies on the use of chemical insecticides. However, overuse of chemical pesticides lead to the development of pest resurgence, secondary pest outbreak, development of resistance and environmental as well as hazards to human health. The three main characteristics that make pheromone feasible for pest management includes its species-specific nature, requirement in low dose as compare to insecticides and non-toxic to non-target animals. Insects that use to be covered under protective coverings like those of bagworms and wood borers particularly are hard to be controlled using chemical sprays. Pheromone baited mass trapping can be useful in this regard. Despite of such advantages, pheromone based pest management is still developing in a very slow rate. Witzgall (2010) suggests lack of motivation and determination for this slow development in pheromone based pest management (47). Although sex pheromones have been utilized in controlling several field crop pests, their use is still limitedly known in plantation crops such as tea. Sex pheromones of tea pests like *Helopeltis theivora*, tea flushworm have been studied and can be incorporated into integrated tea pest management. (62).

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