

## Commercialization of Pheromone Research

### & their application in Indian Agriculture

The dependence on synthetic pesticides has increased



substantially after the advent of green revolution in India to sustain the increasing demand for food production for the growing population. The un-realistic and injudicious use of synthetic pesticides for the past several years led to the outbreak of insect-pests. There has been realization on the importance of efficient monitoring systems of which insect pheromones (chemical communication systems) were found effective in many crop pests. Sex pheromones for a few of the insect pests have been identified, synthesized and successfully field-tested during the past decade in India. There is yet a lot of scope to work on different aspects of use of pheromone technology for its optimal use.

### Categories of pheromones

Pheromones are sub-divided into three categories, on the basis of interaction mediated, as alarm, aggregation and sex pheromones. Sex pheromones generally originate from females and attract males for mating. Aggregation pheromones may or may not be produced by either sex to congregate the species for feeding or reproduction and alarm pheromones serve to rapidly disperse a group of insects usually as a response to predation. It is the sex pheromone of insects that are of particular interest to integrated pest management (IPM) practitioners in agriculture.

## Research and applications of pheromone

### Basic studies

Intensive work has been done on the basic aspects of the sex pheromones in various insects and mammals in India since 1980. Majority of the information is on the location of sex pheromone glands, occurrence of sex pheromones etc. These basic studies have given a fillip to the further studies on the pheromone work.

### Synthesis of Pheromone

The chemistry part of the pheromones is in its developing stage in India as sophisticated instruments are required for taking up of isolation, identification and synthesis of pheromones. Very few laboratories such as Pheromone groups of IICT, Hyderabad, Organic chemistry group of SPIC, Organic chemistry group of BARC have such facilities in India. Some work on the sex pheromone of the crop pests in India has been taken up in collaboration with foreign scientific organizations such as NRI, London; TNO, Delft, Netherlands and CID, CSIC, Barcelona, Spain etc.

**Table 2:** Synthesis of sex pheromones in India

#### IICT, Hyderabad (CSIR):

Sr. No:	crop	Insect	Pheromones
1	Polyphagous (Many crops)	<i>Amsacta albistriga</i> Red hairy caterpillar (Lepidoptera: Arctiidae)	Octadecanal (1.0) (Z <sub>9</sub> Z <sub>12</sub> )-Octadecadienal (1.0) (Z <sub>9</sub> Z <sub>12</sub> Z <sub>15</sub> )-Octadecatrienal (11.5) (Z <sub>3</sub> Z <sub>6</sub> Z <sub>9</sub> )-Heneicosatriene (24.0)
2	Polyphagous (Many crops)	<i>Diacrisia obliqua</i> Bihar hairy caterpillar (Lepidoptera: Arctiidae)	Z <sub>3</sub> Z <sub>6</sub> cis-9,10-epoxy – Heneicosadiene (1.0) (Z,Z)-1,3,6-cis –9,10-epoxy- Heneicosatriene (Z <sub>9</sub> Z <sub>12</sub> )-Octadecadienal (1.0) (Z <sub>3</sub> Z <sub>6</sub> Z <sub>9</sub> )-Heneicosatriene (2.6)
3	castor	<i>Achaea janata</i> Castor semi-looper (Lepidoptera: Noctuidae)	Heneicosane (1.0) (Z <sub>9</sub> Z <sub>12</sub> )-Octadecadienal (1.0) (Z <sub>6</sub> Z <sub>9</sub> )-Heneicosadiene(1.0) (Z <sub>3</sub> Z <sub>6</sub> Z <sub>9</sub> )-Heneicosatriene (60/70)
4	Teak	<i>Hyblaea puera</i> Teak defoliator (Lepidoptera: Noctuidae)	Decadienyl acetate Pentadecadiene acetate Heptadecenyl acetate
5	Teak	<i>Hapalia machaeralis</i> Teak defoliator (Lepidoptera: Pyralidae)	Decadienyl acetate Pentadecenyl acetate Pentadecadienyl acetate
6	Mango	<i>Orthaja exvinacea</i> Mango leaf webber (Lepidoptera: Noctuidae)	Pentadecadienyl acetate

7	Coconut	<i>Nephatis serinopa</i> Black headed caterpillar (Lepidoptera: Xylorectiidae)	Heptadecenyl acetate Heptadecadienyl acetate
8	Sorghum	<i>Atherigona soccata</i> Sorghum shoot fly (Diptera: Anthomyiidae)	1,2 Dimethyl cyclopentane Methyl cyclohexane Dihydro – paracymene Limonene 2,4-Diphenyl-4-methyl –2 (E)- pentene
PROCESS KNOW-HOW OF PHEROMONE SYSTEMS DEVELOPED AND AVAILABLE AT IICT			
9	Polyphagous (Many crops)	<i>Helicoverpa armigera</i> (American Bollworm)	Z11-Hexadecenal
10	Cotton	<i>Pectinophora Gossypiella</i> (Pink bollworm)	Z7Z11-Hexadecadienyl acetate Z7E11-Hexadecadienyl actate(1:1)
11	Cotton and Brinjal	<i>Earias vitella</i> (Spotted Bollworm)	(E,E)10,12-Hexadecadienal Z11-Hexadecenal Z11-Octadecenal (10:2:2)
12	Cotton	<i>Earias insulana</i> (Spiny bollworm)	(E,E) 10,12-Hexadecadienal
13	Rice	<i>Scirpophaga incertulas</i> (Yellow stem borer)	Z11-Hexadecenal Z9-Hexadecenal (3:1)
14	Groundnut, Soybean	<i>Aproaerema modicella</i> (Groundnut leaf miner)	(Z,Z)7,9-Decadienyl acetate E7-Decenyl acetate Z7-Decenyl acetate(10:2.0:1.4)
15	Brinjal	<i>Leucinodus orbanalis</i> (Brinjal shoot & fruit borer)	E11-Hexadecenyl acetate E11-Hexadecenal (10:1.0)

(Source: Yadav et al., 2004)

#### CCRI, Chikmagalur

1	Coffee	Coffee White Stem Borer ( <i>Xylotrechus quadripes</i> )	(S)-2- hydroxy-3-decanone, (R)- 3-hydroxy-2-decanone and 2,3- dihydroxy octane
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(Source: Jayarama et al., 2004)

#### BARC, Mumbai

1	Sweet potato	sweet potato Weevil <i>Cylas formicarius</i>	(Z) –3-Dodecenol-(E)-2- butenoate
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(Source: BARC web site)

The area and the potentials of the major insects of the target crops are given in Table 3.

**Table 3:** The area and the potentials of the major insects of the target crops

Crop	Area in Million hectares			Damage Potential of key pest	References
	2000	2001	2002		
Cotton	8.71	8.58	8.70	39 to 60 %	Panchabhavi et al., 1990.
Pigeon pea	3.43	3.63	3.38	4.0 to 28.0%	Rangaiah-PV; Sehgal-VK,1984 Patnaik-HP; Samalo-AP; Samalo-BN.1986.
Sorgham	10.25	9.86	9.93	5.0 to 50%	Jotwani-MG.1979 Kundu-GG; Jotwani-MG.1977
Bajra	8.9	9.83	9.55	60 and 62%	Taneja-SL; Nwanze-KF.1989.
Rice	45.16	45.71	44.62	21 to 51%	Pasalu et al., 2004.
Groundnut	6.87	6.56	6.40	50 to 92%	Logiswaran and Mohanasundaram, 1985 Abdul-Kareem and Subramanian, 1976 Krishnanand and Kaiwar, 1965
Castor	0.78	1.08	NA	100%	Our unpublished data
Brinjal	0.5	0.51	NA	10-50%	Kumar-NKK; Sadashiva-AT.1996.
Banana	0.49	0.50	NA	Rs.10,000 to 30,000 per acre	Padmanaban et al., 2004
Coconut	1.77	1.87	1.89	34 to 69 %	Kapadia-MN.1981.

In India, monitoring of the key insect-pests such as *H. armigera*, *S. litura*, *P. gossypiella*, were undertaken in the 1980. Intensive work has been done on these insects spreading over Karnataka, Haryana, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Maharashtra, Himachal Pradesh, Punjab and Gujarat (Table 4). Pheromone as a mass trapping tool have also been utilized in a few insects such as *Pthorimoaea opercullela*, *S. litura*, *Chilo*



*sacchariphagus indicus*, *H. armigera*, *A. modicella*, *Lymantria obfusata* Wlk (Porthetria dispar), Tortricid *Cydia pomonella* (L.), Codling moth, *Cydia pomonella*, and *Pectinophora gossypiella* (Saund.) (Table 5). The communication disruption as a tool has been tried in *S. litura*, *A. modicella*, *Peripleneta americana* and *Chilo auricilius* in India with limited

success. Attempts were made to design the trap for efficient trapping of the target insect, some of them were successful in the case of cotton, sugarcane and groundnut ecosystem (Table 6).

### **Monitoring of insect-pests with pheromones**

The occurrence of the major insect pests is difficult to forecast unless it is noticed in a damaging proportion. Hence monitoring of the insect pests using various gadgets becomes imperative. Various traps are used in different situations based on the behaviour of the target insects. Light trap for adults of Lepidoptera, Coleoptera; sticky trap for aphids, laser light traps are for house fly; micro-Lepidoptera, thrips etc. Now the emphasis is on the use of pheromones. Pheromone traps are being used for all the major Lepidopteran insects, Coleoptera, Diptera etc. In the monitoring programme it is very important to recommend the required number of the traps to be used per unit area. The management options have to be decided based on the trapping efficiency, and number of insects trapped. Careful consideration is to be given to the availability of the host plant, the mode of pupation, occurrence of natural enemies of the target insects etc. Lot of research has to be done before recommending the number of traps to be used/unit area.

The principal use of insect sex pheromones is to attract insects towards traps for detection and determination of temporal distribution. Synthetic pheromone lures are available mostly for the adult moth stages of many insects (like rice stem borer, leaf folder, cotton bollworms, black cutworm, tomato pinworm, beet armyworm, cabbage looper, diamondback moth, variegated cutworm, potato tube worm etc), few Dipterans and Coleopterans. The presence or absence of a particular type of pest might indicate a need for additional sampling or the beginning or ending of spraying for the season. By monitoring, the best time to apply insecticides could be predicted and thus reducing insecticide application and there by production costs. Pheromone traps can be used to detect both the presence as well as the density of pest species. Insect populations can thus be estimated and new areas of infestation could be detected at a very early stage. The trap catches may be used to forewarn outbreaks of important pests.

Trap catches also indicate a loss of effect of pheromone on mating disruption and the need to reapply a pheromone treatment. Careful monitoring and experience in interpreting collected data is important for successful implementation of pest management. Information collected from insect monitoring has led to the development of pest forewarning system.

**Table 4: Monitoring**

<b>Species</b>	<b>Area</b>
<i>H. armigera</i> (Noctuidae:Lepidoptera)	23 locations in India
	Karnataka
	Haryana
	M.P.
	T. Nadu
	A.P.
	Maharashtra
	Himachal Pradesh
	Punjab
	Gujarat
	T.Nadu
	Pantnagar, Uttaranchal
	Udaipur
<i>Spodoptera litura</i> (Noctuidae:Lepidoptera)	Karnataka
	U.P.
	T. Nadu
	A.P.
	W.Bengal
	Orissa
	A.P.
	Haryana
	Maharashtra
	Gujarat
<i>Pthorimoaea operculella</i> (Zeller) (Gelechiidae:Lepidoptera)	Mehalaya
	Maharashtra
	Karnataka and T. Nadu
	Simla
<i>Pectinophora gossypiella</i> (Saunders) (Gelechiidae:Lepidoptera)	Maharashtra
	T. Nadu
	Haryana
	Karnataka
	Punjab
	U.P.
	M.P.
<i>Earias insulana</i> Boisd <i>Earias vittella</i> (Farbricius) (Noctuidae:Lepidoptera)	Karnataka
	M.P.
	Maharashtra
<i>Aproaerema modicella</i> (Dev.)	Gujarat

(Gelechiidae:Lepidoptera)	
	M.P.
<i>Chilo partellus</i> (Swinhoe) (Pyralidae:Lepidoptera)	M.P.
<i>Bactrocera cucurbitae</i> (Coquillett) (Tephritidae:Diptera)	Maharashtra
<i>Archips pomivora</i> Meyrick (Lepidoptera: Tortricidae)	Himachal Pradesh
<i>Cylas formicarius</i> (Coleoptera: Brentidae)	Maharashtra
	Kerala
<i>Rhynchophorus ferrugineus</i> F. (Curculionidae:Coleoptera)	Kerala
	Karnataka
	Karnataka
<i>Hellula undalis</i> Fabricius (Pyralidae:Lepidoptera)	India
<i>Scirpophaga incertulas</i> Walk. (Pyralidae: Lepidoptera)	India
	Hyderabad
	Hyderabad
	Orissa
	Karnataka
	Gujarat
<i>Xylotrechus quadripes</i> Chev. (Cerambycidae: Coleoptera)	India
<i>Leucinodes orbonalis</i> (Guenee) (Pyralidae:Lepidoptera)	India
	Anand
<i>Opisina arenosella</i> Walk. (Cryptophasidae:Lepidoptera)	India
<i>Maruca vitrata</i> Fabricius (Pyralidae:Lepidoptera)	India
<i>Sitotroga cerealella</i> (Olivier) (Gelechiidae: Lepidoptera).	India
<i>Cydia pomonella</i> (L.) (Tortricidae :Lepidoptera)	Kashmir
	Himachal Pradesh
	Himachal Pradesh
Banana corm weevil, <i>Cosmpolites sordidus</i> (Germer)	Tiruchirapalli
Banana stem weevil, <i>Odoiporus longicollis</i>	Tiruchirapalli
Cardamom shoot and capsule borer, <i>Conogethes punctiferalis</i> G.	TamilNadu
Sugarcane early shoot borer, <i>chilo infuscatelusi</i> S.	Anakapalle
Cigarette Beetle, <i>Lasioderma serricorne</i>	Hyderabad

## Mass Trapping

This is a direct method of managing the insects. Based on the number of insects trapped, a decision can be taken to continue the recommended number of traps/unit area for mass trapping or remove all the traps and use only for monitoring. Because, if the anticipated insects are going to occur only below ET levels, there is no need for continuing the traps meant for mass trapping thus reducing the costs. If the population is of moderate level, mass trapping followed by application of bio-pesticides would be sufficient to contain the insect before reaching economically important level. If the insect is occurring in an endemic way, necessarily, we have to think of going in for an integrated approach to manage the pest.

**Table 5: Mass Trapping**

Species	Location
<i>Pthorimoaea opercullela</i> (Zeller) (Gelechiidae:Lepidoptera)	Karnataka and T.Nadu
	Karnataka
	New Delhi
	U.P.
	Punjab
<i>Chilo auricilius</i> Dudgeon (Crambidae: Lepidoptera)	U.P., Haryana
<i>S. litura</i> (Noctuidae:Lepidoptera)	U.P.
	A.P.
	T.Nadu
	Gujarat
	Gujarat
<i>H. armigera</i> (Hub.) (Noctuidae:Lepidoptera)	A.P.
	Gujarat
	Haryana
	Gujarat
	Madurai
	Madurai
	Gujarat
	Gujarat
<i>Aproaerema modicella</i> (Dev.) (Gelechiidae:Lepidoptera)	Gujarat
	Andhra Pradesh
	Hyderabad
<i>Lymantria obfuscata</i> Wik	Kashmir

( <i>Porthetria dispar</i> ) (Lymantriidae: Lepidoptera)	
	India
<i>Cydia pomonella</i> (L.) (Lepidoptera: Tortricidae)	Kashmir
	Ladakh
<i>Pectinophora gossypiella</i> (Saunders) (Gelechiidae:Lepidoptera)	Tamil Nadu
	Madurai
	Madurai
	Gujarat
<i>Periplaneta americana</i> L. (Blattidae:Dictyoptera )	Karnataka
Rhinoceros beetle <i>Orcytes rhinoceros</i>	Andhra Pradesh
Red Palm Weevil, <i>Rhynchophorus ferrugineus</i> Oliver	Goa
	Bangalore
<i>Scirpophaga incertulas</i> Walk. (Pyralidae: Lepidoptera)	west Godavari, Nizamabad
	Hyderabad
Coffee white stem borer <i>Xylotrechus quadripes</i>	Karnataka
<i>Chilo sacchariphagus indicus</i> (Kapur)	Karnataka
<i>Scirpophaga excerptalis</i> walker	Karnataka
<i>Chilo infuscatellus</i> Snellen	Karnataka
<i>Batocera dorsalis</i> H.	Gujarat
	Gujarat
Banana stem weevil, <i>Odoiporus longicollis</i>	Tiruchirapalli
	Tiruchirapalli
Spotted boll worm, <i>Earias</i> spp.	Madurai
	Madurai
	Gujarat
<i>Leucinodes orbonalis</i> (Guenee) (Pyralidae:Lepidoptera)	Gujarat

### Mating disruption

With the commercial availability of insect sex pheromones for several agricultural pests in the 1970s, scientists and entrepreneur turned their attention to mating disruption as a “biorational” approach for insect control. Emission of pheromone is relatively low from each source such that a down wind trail is created and not lost in the background of released pheromone. Males following these trails are thought to spend their mating energies in pursuit of artificial pheromone sources.

## Mechanism of mating disruption

Male confusion is thought to be the result of ambient pheromone concentrations sufficient to hide the trails of calling females (large doses from diffuse sources such as microcapsules or larger doses of pheromone in point source dispensers such as tie-on polyethylene rope). Added to the effect, is the adaptation of antennal receptor sites and for habituation of the insect's central nervous system. Specific receptor sites on the antennae respond to only the pheromone molecules. When a receptor site is continually activated by high ambient concentrations of pheromones, the resulting electrical signal diminishes (measured by an electroantennogram). The receptor site becomes unresponsive and the insect becomes navigationally blink. When the insect's central nervous system is inundated with signals from the receptor sites, it becomes habituated and no longer is able to provide the directed behaviour. The net result of confusion is that the male is unable to orient to any pheromone source and follow the upwind trail to a mate.

### **Some possibilities of the mechanism of the confusion approach as put forth by Pedigo (2002) include:**

- Camouflage or covering up the natural pheromone scent of females
- Misdirection of males to scents from multiple point sources of synthetic pheromone, and
- Adaptation/habituation by desensitizing male antennal receptors through constant pheromone-like exposure

The first preliminary field test demonstrating the potential of this approach was conducted in 1967 with the cabbage looper, *Trichoplusia ni*. In this test, pheromone concentrations were shown to thwart males from being lured to female moths. Following this success, many studies were conducted to apply the approach but with little success. These included work with fruit, vegetable, field, forest and stored product pests. In these studies, pheromone dispensing seemed the greatest obstacle to success.

Subsequently, controlled-release dispensers were developed, and these have paved the way for successes in pest suppression. One such type of dispenser is the Hercon<sup>®</sup> flake, produced by Hercon Environmental Company. Hercon flakes are multilayered plastic laminates, about 3 mm<sup>2</sup> (1/8 in.<sup>2</sup>), that contain pheromone in the inner layer, or reservoir. The outer layers of the flake serve as a protective barrier but allow the mixture to diffuse into the air. As the material is dissipated into the air, a replacement quantity automatically

moves outward from the reservoir to maintain the desired surface concentration and to give long-lasting effectiveness. The flakes are applied somewhat like a conventional insecticide with the use of a special device, the Hercon dispenser pod, attached to an airplane. This unit automatically combines the flakes with a special sticker that causes them to adhere to foliage as they land.

### **Mating disruption technique in Indian Agriculture**

In a very few cases mating disruption technique was successful in India. Based on the information's available, communication disruption may be successful in crops where dense foliage results in reduced wind velocity and thus pheromone persists for a few hours. Some examples are *Chilo auricilius* Dudgeon (Crambidae: Lepidoptera) in sugarcane in U.P. (Nesbitt *et al.*, 1980), *Proaerema modicella* (Dev.) (Gelechiidae: Lepidoptera) in pigeon pea intercropped with groundnut in T.N. (Nandagopal *et al.*, 2001), *S. litura* (Fabricius) (Noctuidae: Lepidoptera) in groundnut in A.P. (Srinivas and Rao, 1993; Rao *et al.*, 1989), *Scirpophaga incertulas* Walk (Pyralidae: Lepidoptera) in rice ecosystem in A.P. (Pasalu *et al.*, 2004).

### **Delivery system of the pheromone**

The delivery system is very important for release of pheromone for longer period to avoid lure replacement within a short period (now it is within 21 days). There are several delivery systems available for the mating disruption. Some of them are rubber septa, plastic laminate, hollow fiber, polyethylene tube, PVC resins, sprayable polymer beads, sprayable hollow fibers, sprayable micro-encapsulations etc.

The microencapsulated pheromone offers the advantage of both utilizing the conventional pesticides application equipments and of distributing pheromones in a relatively uniform manner. The other option is to use micro-dispersible technique, hollow fiber dispensers applied with a modified spray procedure, appears to obviate the difficulty of maintaining the required emission rate, since longevity of emission depends on the length of the fiber.

### **Trap design**

Limited information is available on the development of traps for various insects in Indian agriculture. Efficient traps were designed for groundnut leaf miner; *H armigera* Sugarcane internode borer, *Chilo sachariphagus indicus*; for *Spodoptera litura*. The efficiency of

these traps was between 60 to 90%. The trap and the lures used for *H. armigera* attracted the *Pectinophora* males in pigeon pea ecosystem.

**Table 6: Trap design**

Species
<i>Pectinophora gossypiella</i> (Saunders) (Gelechiidae:Lepidoptera)
<i>H. armigera</i> (Hub.) (Noctuidae:Lepidoptera)
<i>Sitotroga cerealella</i> (Olivier) (Gelechiidae: Lepidoptera).
<i>S. litura</i> (Noctuidae:Lepidoptera)
<i>Chilo sachariphagus indicus</i> Kapur (Pyralidae:Lepidoptera)
<i>Aproaerema modicella</i> (Dev.) (Gelechiidae:Lepidoptera)
<i>Bactrocera dorasalis</i> walker

### Present status of Pheromone Research in India

Most of the Indian research work has been focused on monitoring the pest incidence followed by mass trapping with negligible emphasis on mass trapping. In cereals, eight insects are being monitored using the pheromone of which yellow stem borer (*Scirphophaga incertulas*) leaf folder (*cnaphalocrocis medinalis*) and maize stalk borer, (*Chilo partellus*) are important. Attempts were made to use pheromone for mass trapping and mating disruption only in *S. incertulas*. Among the cotton pests pink bollworm (*Pectinophora gossypiella*), spotted bollworms (*Earias* spp.) and gram pod borer (*Helicoverpa armigera*) are important (Table 7). The first two species were targeted for the mass trapping and mating disruption technique. In oilseeds, seven insects are being included for monitoring, and for mass trapping the groundnut leaf miner (GLM), the tobacco caterpillar were tried. Mating disruption with saturation of sex pheromone was tried in GLM. The pheromone chemicals were identified for castor semilooper (*Achaea janata*), red hairy caterpillar (*Amsacta albistriga*) and Bihar hairy caterpillar (*Diacrisia oblique*). The actual work using the pheromones is yet to be started. In vegetables nine insects were under observation using pheromones. Of these brinjal borer (*Leucinodes orbonalis*) is the main insect that attracted international working group for tackling through pheromone. In sugarcane, six insects were targeted of which sugarcane stalk borer (*Chilo auricilius*) in North India and early shoot borer (*Chilo infuscatellus*) and internode borer (*Chilo sacchariphagus indicus*) in South India causing havoc in sugarcane cultivation. In

tree crops shoot and panicle borer of cardamom, turmeric and ginger, *Dichocrocis punctiferalis*, red palm weevil (RPW), (*Rhynchophorus ferrugineus* Oliver) and coffee white stem borer (*Xylotrechus quadripes*) were tried for monitoring and mass trapping.

**Table 7. Present Status of Pheromone Research in India**

No.	Pest species	Pheromone components	Method of use
	CEREALS		
1.	Yellow stem borer, <i>Scirphophaga incertulas</i>	Hexadecenal (Z)-9- Hexadecenal (Z)-11- Hexadecenal (Z)-11- Hexadecen-1-ol (Z)-9- Octadecenal	Monitoring, Mass trapping and mating disruption
2.	Leaf folder, <i>Cnaphalocrocis medinalis</i>	Hexadecyl acetate (Z)-11-Hexadecenyl acetate Octadecyl acetate (Z)-13-Octadecenyl acetate	Monitoring
3.	Leaf folder, <i>Marasmia patnalis</i>	(Z)-13-Octadecenyl acetate (Z)-11-Hexadecenyl acetate	Monitoring
4.	Maize stalk borer, <i>Chilo partellus</i>	(Z)-11- Hexadecenal (Z)-11- Hexadecen-1-ol	Monitoring
5.	Striped stem borer, <i>Chilo suppressalis</i>	Hexadecenal (Z)-9- Hexadecenal (Z)-11- Hexadecenal (Z)-11- Hexadecen-1-ol Octadecan-1-ol (Z)-11- Octadecenal	Monitoring
6.	Climbing cutworm, <i>Mythimna separata</i>	(Z)-11-Hexadecenal (Z)-11- Hexadecen-1-ol (Z)-11-Hexadecenyl acetate	Monitoring
7.	Purple stem borer, <i>Sesamia inferens</i>	(Z)-11-Hexadecenyl acetate (Z)-11- Hexadecen-1-ol (Z)-11-Hexadecenal	Monitoring
8.	Rice green caterpillar, <i>Naranga aenescens</i>	(Z)-9-Tetradecenyl acetate (Z)-9-Hexadecenyl acetate (Z)-11-Hexadecenyl acetate	Monitoring
	COTTON		
9.	Pink bollworm, <i>Pectinophora gossypiella</i>	(Z,Z)-7,11-Hexadecadienyl acetate (Z,E)-7,11-Hexadecadienyl acetate	Mass trapping, Monitoring and mating disruption
10.	Spotted bollworm, <i>Earias vittella</i>	(E,E)-10,12-Hexadecadienal (E,E)-10,12-Hexadecen-1-ol Z11-Hexadecenal Z11-Octadecenal	Mass trapping, Monitoring and mating disruption
11.	Spiny bollworm, <i>Earias insulana</i>	(E,E)-10,12- Hexadecadienal	Mass trapping, Monitoring and Mating disruption

12.	Gram pod borer, <i>Helicoverpa armigera</i>	(Z)-9- Hexadecenal (Z)-11- Hexadecenal Hexadecenal (Z)-11-Hexadecen-1-ol Hexadecan-1-ol	Monitoring and mass trapping
13.	Oriental tobacco budworm, <i>Helicoverpa assulta</i>	Hexadecenal (Z)-9- Hexadecenal (Z)-11- Hexadecenal Hexadecencyl acetate (Z)-9- Hexadecencyl acetate (Z)-11- Hexadecencyl acetate Hexadecen-1-ol (Z)-9-Hexadecen-1-ol (Z)-11-Hexadecen-1-ol	Monitoring and mass trapping
14.	Tobacco caterpillar, <i>Spodoptera litura</i>	(Z)-9(E)-11-Tetradecadienyl acetate (Z)-9(E)-12-Tetradecadienyl acetate	Monitoring and mass trapping
	OILSEEDS		
15.	Castor semi looper, <i>Achaea janata</i>	(Z,Z)-6,9-Heneicosadiene (Z,Z,Z)-3,6,9-Heneicosatriene (Z,Z)-9,12-Octadecadienal	Chemicals identified
16.	Red hairy caterpillar, <i>Amsacta albistriga</i>	Octadecanal (Z,Z)-9,12-Octadecadienal (Z,Z,Z)-9,12,15-Octadecatrienal (Z,Z,Z)-3,6,9-Heneicosatriene	Chemicals identified
17.	Groundnut leaf miner, <i>Aproaerema modicella</i>	(Z)-7-Decenyl acetate (E)-7-Decenyl acetate (Z)-7,9-Decadienyl acetate	Monitoring and mass trapping, mating disruption
18.	Bihar hairy caterpillar, <i>Diacrisia oblique</i>	(Z,Z)-3,6-cis-9,10-Epoxy-3,6- heneicosadiene(Z,Z)-3,6-cis-9,10- Epoxy-1,3,6- heneicosatriene (Z,Z)-9,12-Octadecadienal (Z,Z,Z)-9,12,15-Octadecatrienal (Z,Z,Z)-3,6,9-Heneicosatriene	Chemicals identified
19.	Tobacco caterpillar, <i>Spodoptera litura</i>	(Z)-9(E)-11-Tetradecadienyl acetate	Monitoring and mass trapping
20.	Red palm weevil, <i>Rhynchophorus ferrugineus</i>	(4S,5S)-4-methyl-5-nonanol (4S)-4-methyl-5-nonanone	Monitoring and mass trapping
21.	Rhinoceros beetle, <i>Orcytes rhinoceros</i>	Ethyl-4-methyloctanoate Ethyl-4-methylheptanoate 4-Methyloctanoic acid	Monitoring and mass trapping
	VEGETABLES		
22.	Diamond-back moth <i>Plutella xylostella</i>	(Z)-11-Hexadecenal (Z)- 11 -Hexadecenyl acetate (Z)-11-Hexadecen-1-ol	Monitoring and mass trapping
23.	Cabbage stem borer, <i>Hellula undalis</i>	(E, E)-11, 13 - Hexadecadienal	Monitoring
24.	Brinjal borer, <i>Leucinodes orbonalis</i>	(E)- 11-Hexadecenyl acetate (E)- 11-Hexadecen-1-ol	Monitoring and mass trapping

25.	Cutworm, <i>Spodoptera exigua</i>	Tetradecyl acetate (Z)-9-Tetradecenyl acetate (Z)-11-Tetradecenyl acetate (Z,E)-9,12-Tetradecadienyl acetate (Z,Z)-9,12-Tetradecadienyl acetate (Z)-9-Tetradecen-1-ol	Monitoring and mass trapping
26.	Tobacco caterpillar, <i>Spodoptera litura</i>	(Z)-9(E)-11-Tetradecadienyl acetate	Monitoring and mass trapping
27.	Gram pod borer, <i>Helicoverpa armigera</i>	(Z)-9- Hexadecenal (Z)-11- Hexadecenal Hexadecenal (Z)-11-Hexadecen-1-ol Hexadecan-1-ol	Monitoring and mass trapping
28.	<i>Earias</i> sp.	(E,E)-10,12-Hexadecadienal (E,E)-10,12-Hexadecen-1-ol Z11-Hexadecenal Z11-Octadecenal (E,E)-10,12- Hexadecadienal	Mass trapping, Monitoring and mating disruption
29.	Potato tuber moth, <i>Phthorimaea operculella</i>	(E, Z)-4,7-Tridecadienyl acetate (E, Z, Z)-4,7,10-Tridecatrienyl acetate	Monitoring
30.	Sweet potato weevil, <i>Cylas formicarius</i>	(Z)-3-Dodecenol-(E)-2-butenolate	Mass trapping, Monitoring and mating disruption
	SUGARCANE		
31.	Sugarcane stalk borer, <i>Chilo auricilius</i>	(Z)-7-Dodecenyl acetate (Z)-8-Tridecenyl acetate (Z)-9-Tetradecenyl acetate (Z)-10-Pentadecenyl acetate	Monitoring
32.	Early shoot borer, <i>Chilo infuscatellus</i>	(Z)-11-Octadecen-1-ol	Mass trapping and mating disruption
33.	Internode borer, <i>Chilo sacchariphagus indicus</i>	(Z)-13-Octadecenyl acetate (Z)-13-Octadecen-1-ol	Mass trapping
34.	<i>Scirpophaga excerptalis</i>	E-11-Hexadecenal Z-11-Hexadecenal	Monitoring
35.	Armyworm, <i>Mythimna separata</i>	(Z)-11-Hexadecenal (Z)-11- Hexadecen-1-ol (Z)-11-Hexadecenyl acetate	Monitoring
36.	Purple stem borer, <i>Sesamia inferens</i>	(Z)-11-Hexadecenyl acetate (Z)-11- Hexadecen-1-ol (Z)-11-Hexadecenal	Monitoring
	TREE CROPS		
34.	Shoot and panicle borer of cardamom, turmeric and ginger, <i>Dichocrocis punctiferalis</i>	(E)-10-Hexadecenal (Z)-10-Hexadecenal	Monitoring and mass trapping

35	Red Palm Weevil (RPW), ( <i>Rhynchophorus ferrugineus</i> Oliver)	Ferrugineol	Mass trapping
36	coffee white stem borer <i>Xylotrechus quadripes</i>	(s)-2-hydroxy-3-decanone	Monitoring

(Source: Cork and Hall, 1998)

### Scope for commercialization

For synthesis of the components of pheromones of all the major insects the following centres of excellence and commercial establishments can be approached:

- 1) Indian Institute of Chemical Technology (CSIR), Hyderabad (Dr.J.S.Yadav and his team).
- 2) Central Coffee Research Institute Coffee Research Station-577117, Chikmagalur Dist Karnataka, India ( Dr.Jayarama and others)
- 3) Baba Atomic Research Centre, Mumbai
- 4) Indian Lac Research Institute (ICAR), Ranchi

### Field experiences

Some of vital information on the pheromone uses by clientele level, manufacturers level, experimenter level and synthesis level were collected personally, through discussions, literatures, field visits. This information is so vital that if they are rectified/improved, the use of pheromone as commercial product will go along way in India agriculture.

#### a) Installation of the trap and fixing of lure in the field

- Poor quality rubber band which tied around the neck and bottom of the sleeve of the trap
- Improper fixing of trap, tilting on one side allowing visiting insects to escape
- Poor quality plastic sleeve which run for one month becoming brittle and tear off
- Improper fixing of lures in the trap
- The bottom of the sleeve is not tied properly with the stick

- Very thin or damaged bamboo sticks which can not with stand heavy winds

#### **b) Researchable**

- There should be thorough experimentations on the trap designs to be used for various species of insects as they differ in their trapability
- Proper ratios of the various components of the pheromone for various agro-climatic zone for a particular species should be examined
- There should be experimentations on the use of a particular component for more than one species of the insects so that the multiplicity of the traps in a unit of cropped area can be avoided
- Durability of the traps/ sleeves and delivery system of the pheromones should be evaluated thoroughly before recommendation to large scale manufacturing by the industries
- There should be development of standard trapping system for each insect encompassing trapability distance, trap density/unit area, minimum load of the pheromone components, placement of the trap, longevity of the lures and traps
- The correct delivery system should for each of the insects should be devised
- Experimentation on the minimum distance between any two traps should be found out to minimise the number of traps to be used per unit area

#### **c) For Industries**

- Proper quality of the materials for the manufacturing the traps should be used for longer period in the field conditions
- Proper fixing facilities should be provided in the trap itself so that the farmers can use it properly; Inverted 'L' handle would be more suitable to tie the trap in a single bamboo stick, instead of 'T' shaped bamboo stick
- High purity of the pheromone components should be used for actual blend of the pheromone (above 97%)
- Proper quantity of the pheromone should be loaded in to the delivery system
- The cost factor is very important for the resources poor farmers
- Supply of the pheromone traps and lures should be nearest to the farmers
- Instructions with flow pictures for proper installation of the traps and lures should be supplied along with the pheromone traps

#### **d) For extension agency**

- There should be regular training for the extension agencies on the installation and the methods adopted on the monitoring, mass trapping and communication disruption of the insects using the pheromones
- The extension agency should explain the farmers about the proper installations of the traps and the actual number of traps /unit area
- Proper advise to farmers on the timing of use of the pheromone is necessary

#### **e) For farmers**

- Fresh lures should be purchased every time and lures should not be kept in room temperature, instead, if there is facilities like refrigerators, lures in a plastic bag should be kept in side the deep fridge
- Install the actual number of traps to be used per unite area
- The traps should be installed upright, so that the lure is in correct position and not likely to fall due to wind
- The tying of the sleeve both at the top and at the bottom should be proper to avoid opening of the sleeve and escape of the trapped insects
- Do not allow the trapped insects inside the sleeve for many days as it may facilitate for slow movement and escape of few of the insects
- At least once in a week the trap should be monitored for insects and if found, they should be killed by crushing inside the sleeve itself and by opening the bottom of the sleeve, the killed insects can be removed
- Use strong sticks so that it can withstand the weight of the moths trapped and the strong winds
- While moving inside the field, see that any trap is loosened from its position and sleeve is detached, if found it should be rectified
- If the crop is nearing harvest collect the traps carefully with out damaging the fittings and the sleeves and store them properly so that the same can be used for other pest where similar trap is recommended
- If the neighbouring farmers are also having crops harbouring the same species, should also be encouraged to go for pheromone trapping- community approach
- Remove the lures at least once in 25 to 30 days.

## **Future Requirements**

- Prioritize the present pest status across production system
- Develop efficient monitoring system of ecumenically important insects
- Reduce production cost
- Technical assistance for synthesis of pheromone component, field testing of the pheromone
- Inter-institutional linkage building to generate data on various aspects of pheromone technology
- Training scouts to improve their efficiency
- Periodic workshops to up date and exchange information
- Initiate work on kairomones of important species
- Periodic feed back from land to lab to update/modify the existing technologies

### **A. Basic studies**

1. Elucidation, identification and synthesis of component of pheromone of target insects.  
Bioassay studies on the pheromones using EAG, Wind tunnel etc.  
Combination of lures to trap two or three species compatibility studies

### **B. Monitoring and mass trapping**

- Standardization of number of traps /unit area for different production system.  
Relationships between moths trapped and the life stages of insects vs. damage levels

### **C. Mating disruption**

Male confusion is thought to be the result of ambient pheromone concentrations sufficient to hide the trails of calling females (large doses from diffuse sources such as microcapsules or larger doses of pheromone in point source dispensers such as tie-on polyethylene rope). The net result of confusion is that the male is, unable to orient to any pheromone source and follow the upwind trail to a mate (Flint and Doane, 1996).

### **D. Trap design**

Efficient traps should be designed based on observation on the activity of males/females and fabricated using low cost material available locally.

## Conclusion

Pheromone technology in India is still at infancy and there is lot to be studied before drawing any meaningful conclusions. Since it is a potential technology to help Indian agriculture, government organizations, commercial sector, and non- governmental organizations should give special consideration in development and dissemination. Currently, these compounds are included in general insecticide group. However, considering their special features to be included as an important ecofriendly component IPM. So far most of the developments came from the west. To be self-sustainable, attempts should be made to generate resources to establish in-country research and development base. Future research should be addressing projects on kairomones where the pests are very specific so that direct control can be possible. Periodic capacity building of all partners involved in pheromone activities should be organized. Awareness building among farming community through media and on-farm participatory research also plays critical role in refinement and further dissemination of technology.

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**Note:** The author has used various references in the preparation of this article. For further details please contact him.