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Insect Pheromone: A tool in agricultural pest management

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Abstract

Pests in diverse phases of its lifecycle pose threat to the modern agricultural structure as they destroy crops and food products. To defend crops from pest invasion, to increase food productivity, modern agricultural practices and market available pesticides are used which are highly toxic and environmentally untenable. Broad-spectrum pesticides, apart from damaging target pest, also kill beneficial non-target organisms of different trophic levels. Residual toxicity in different spheres alters the survival of biome-specific macro- and meso-fauna provoking diminution of nutrient mobilization through mineralization processes. The insect pheromones create the network of courtship, mating, and egg-laying and complex social behaviour in their world. The employ of insect species-specific sex pheromones is an alternate biotechnology for integrated pest management in disparity to commercial insecticides, having retrogressive effects on human health and environment and is skilful also against insecticide-resistant insect populations. Pheromones are proficient on low population densities of pest. They do not affect natural non-target organisms and therefore, bring about long-lasting minimization in pest populations below economic injury level which cannot be accomplished with traditional insecticides. Mass trapping and Mating Disruption methods using sex pheromones have significantly attenuated insecticide-related environmental deterioration, thus providing sustainable, eco-friendly bio-tools. The increasing funding on pheromone management and research blooms manifold to encompass negligible environmental effect and thriving effectiveness in pest control. Study of behaviour of pheromone-releasing insects, their life cycles along with biotechnological employment of analytical chemistry, genetics, chemical ecology, neurophysiology, molecular and evolutionary biology has helped us to grasp better the pheromone sensation mechanisms and their implications in agricultural pest management.

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Pest can damage farming, parasitizing domesticated animals, harvest crop market access, the regular eco-habitat, and our way of life[15]. Pests can include weeds, plant pathogens (certain fungi, bacteria, and viruses), rodents, and nematodes notwithstanding the plant-taking care of insect and mites are assessed to annihilate as much as 33% of all farming yield[48]. Synthetic chemicals do not merely attack the pests— they additionally influence the plant ecosystem and the natural equilibrium—because of pollution, biomagnification and destruction of beneficial animals and natural predators of the pests, among different variables—the inevitable conclusion is that the negative ramifications of pesticide use offset the advantages[12]. In the present circumstance, the solution for the immortal fight against pests' lies in coordinated integrated pest management (IPM), a more refined way to deal with. Insect sex pheromones have been foundwell-equipped biological tools for pest recognition and management since the early 1970s[11,73].

Insects interconnect comprehensively through chemical messages (Semiochemicals). Pheromones are semiochemicals used in communication between intra-species, while allelochemicals mediate communication between different species. More than 600 species of lepidopteran pheromones have been identified for pest control[70]. Few families of Lepidopteran with genera producing sex pheromones for pest co ntrol was noted in (Figure 1, Table-1). Their characteristics like species-specificity, non-toxicity to mammals and other helpful organisms, their activity in minimal dose (s), and rapid degradation in the environment created a promising technology for regulating insect pests, approximating pest populations, perceiving the entry and progress of invasive pests, and preserving endangered species[57]. Worldwide diverse pheromones, identified from female moth species, are classified into Type I (75%), Type II (15%), and miscellaneous (10%) groups, according to their chemical structures[59] (Figure 2). Interestingly, many pheromones produced by male moths and butterflies have been known. While new sex pheromones from about 70 lepidopteran species have been reported in the last five years utilizing GC-EAD, LC, GC-MSand NMR, our information about the pheromones is still rudimentary, and these kinds of semiochemicals remain an exciting research target for natural product chemistry[7]. In this review we discussed the most flourishing practical applications of sex pheromones (mostly lepidopterans) in IPM in monitoring pest populations, mass trapping, mating disruption (MD), and push-pull strategies.

Sex pheromones: A layout :

The significant feature of the IPM lies in using natural volatile product (like behaviour-modifying chemicals, BMC), usually released by insects and perceived by other individuals of the same or other species. BMCs, which contain communication components, fall into two major groups: intraspecific utilizing-chemicals and interspecific chemicals. The first group of semio-chemicals are pheromones[40]. They transfer information that induces in the recipient a process of development or change of behaviour. The various sorts of pheromones include types like aggregation, alarm, home recognition, egg-laying deterrent, queen, sex, territorial, trail, and other pheromones[7]. Like all pheromones, sex pheromones are mixtures of several chemicals, species-specificto attract the opposite sex for mating and fertilization (Figure 1)[52,56]. Pheromones alter behaviour of numerous insect pests through a chemical pathway which creates a circle between insects and/or plant(s). It measured an encouraging element in monitoring programs. They are inculcated in different IPM control strategies like monitoring insect pests, MD, mass trapping, and attract-and-kill and push-pull strategies[23].

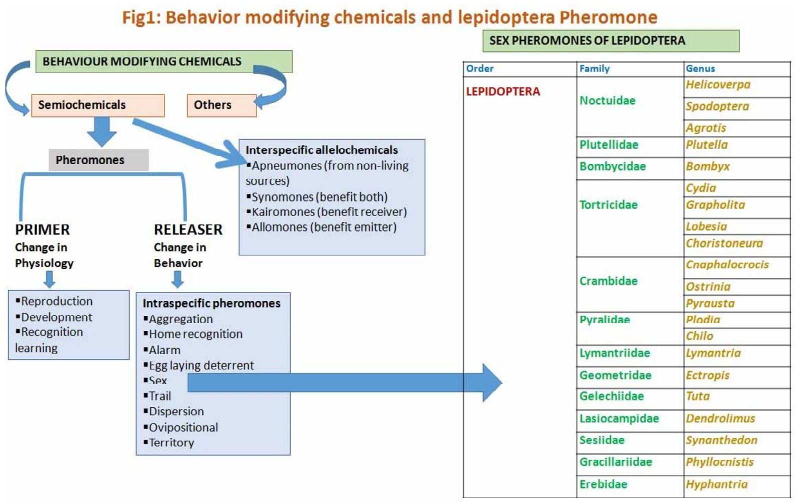
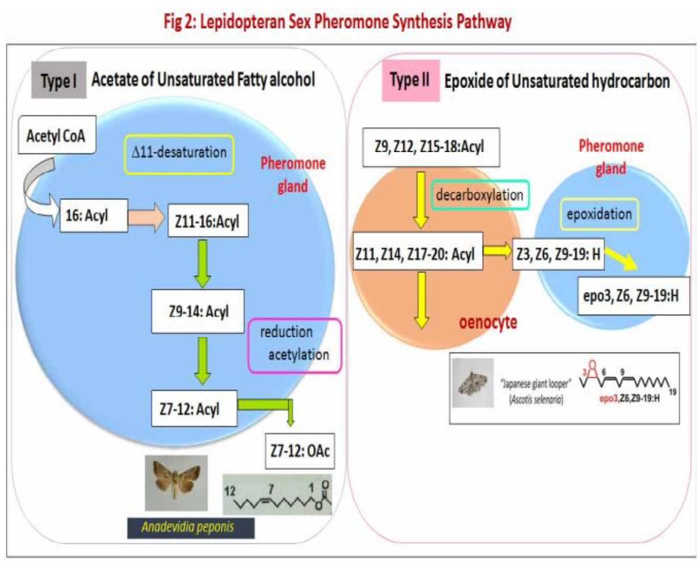


Figure1: Behaviour modifying chemicals and lepidopteran pheromone: Classifications of behaviour modifying chemicals were represented. Different types of pheromones were mentioned. The most cited Lepidopteran sex pheromones of different genera are shown.



Sex Pheromone: Presentation :

The amounts of sex pheromones produced and released to the atmosphere are in the range of nanograms (10^{-9} gram) per insect or less. The first sex pheromone was the silkworm moth (*Bombyx mori*), isolated and published in 1959[51]. Female release the sex pheromone (with active components) in the atmosphere. Males downwind from the females detect the active chemicals and fly upwind in a zigzag course ended few metre distances before finding the source (a "calling female"). The male then takes steps to "convince" the female to mate[40] . The insect organ liable for receiving odours is the antenna. The lipophilic organic molecules of the pheromone, are conveyed to the receptors by proteins within the fluids in the sensory hairs on the antenna. A cascade of chemical and electrophysiological signals is set off towards the receiver[63].

Pheromones are usually unstable in the environment[35], volatile (except contact pheromones), destroy moderately fast and are energetic only when present in the air. They are not noxious to living organisms, most known pheromones being attained from fatty acids, amino acids, terpenes, hydrocarbons, simple aromatic derivatives, and several other chemical groups[41].

Lepidopteran Sex pheromone :

The order Lepidoptera contains an expected 160,000 species, emerged around 140 million years ago, releasing/secreting many bioactive normal products studied in an array of species[7]. Taxonomically related moths depend upon to deliver pheromones with structural comparability, but some dissimilation are inevitable to establish their reproductive incoherence[14]. Their simple chemical structures are assorted for species-specific reproductive segregation of each species and interplay of pheromones. Mostly, moth sex pheromones constituted of two or more elements in an exclusive ratio, and are classified into four groups (Type-0, Type-I, Type-II and Type-III,) according to their site of production, chemical structure, and biosynthetic features (Figure 2). Bombykol, (10*E*, 12*Z*)-hexadeca-10,12-dien-1-ol, is the first pheromone compound identified from females of the silk moth (*Bombyx mori*) about 60 years ago[9]. Most moths are using Type I sex pheromones which are basically long straight chains (C_{10}- C_{18}) alcohol and their derivatives (acetates and aldehydes). Type-II sex pheromones constituted of C_{17}–C_{23} hydrocarbon chain with two or three double bonds at the three, six, or nine positions, or their conforming epoxide byproducts[42] (Figure 2). Type-III sex pheromones has one or more methyl branches with distinct biosynthetic features, and the elements contain unsaturated and C_{17}–C_{23} saturated hydro-carbons, as well as functional hydrocarbons. Type-0 sex pheromones, with secondary alcohol skeleton comparable to some general plant volatile compounds, are utilized by the oldest lineages of Lepidoptera species[31]. Moth sex pheromones are mainly biosynthesized in and secreted from the sex pheromone gland. Type-I gland is located in the inter-segmental membrane between the eighth and ninth abdominal segments[49].

Lepidoptera pheromones: transmission glands :

The males of Lepidoptera produce an odor from glands known as androconia which are located in wings asso-ciated with scales. Androconia have a somewhat lengthened structure and terminates in a row of fine processes called fimbriae. Phero-mones produced by these glands evaporate through these fimbriae[43].

In queen butterfly, *Danaus gilippus*, a pheromone is released by the male and brushed on the female by a pair of brush-like hair pencils. These are present at the tip of the abdomen.On each side of the hind wings of *Amauris* males, there are small scent patches. These patches comprise highly altered struc-tures called scent cups. These scent cups have a median pore and below the scent cup is present a scent gland. From these scent patches, scent is detached by scent brushes associated with genitalia[19].

In *Plaodia*, pheromones are secreted from invaginated glands that open on both side of the last abdominal segment. By evagination of this gland, the odor is dispersed. Female silk moth emits a sex pheromone called bombykol from a pair of sacs called saccule lateralis. It is found on the last abdominal segment[51].

Sex pheromones and their components for insect pest control :

The chemical structure of pheromones is broadly diversified (Table-1). Thus, many of them are alcohols, hydrocarbons, aldehydes, esters, epoxides, lactones, ketones, carboxylic acids, isoprenoids, and triacylglycerides[40]. This structural diversity is the key for the pheromone specificity but, in many species of Lepidoptera, a specific ratio of the pheromone components renders its species-specificity (Figure 1).

Table-1. Recent sex pheromone components identified from insect pests

Pheromone/Pheromone components	Insect genera with families	References
ORDER LEPIDOPTERA		
(E)-11-hexadecenal, (E,E)-10,12-hexadecadienal	*Diaphania glauculalis* (Crambidae) *Diaphania nitidalis* *Diaphania hyalinata* (Pyralidae)	Ma *et al.*, 2015.
(E)-10-hexadecenal, (Z)-10-hexadecenal, (E)-10-hexadecenol, (E,E)-10,12-hexadecadienal, (Z,Z,Z)-3,6,9-tricosatriene	*Conogethes pluto* (Crambidae)	El Sayed *et al.*, 2006
(Z)-11-hexadecenyl acetate, (Z)-11-hexadecenal, (Z)-11-hexadecenol	*Trichophysetis cretacea* (Crambidae)	Peng *et al.*, 2012
(Z)-11-Hexadecenyl trifluoromethyl ketone	*Ostrinia nubilalis* (Pyralidae)	Downham *et al.*, 2004

(E,E)-8,10-Dodecadienyl trifluoromethyl ketone	*Cydia pomonella* (Tortricidae)	Heuskin *et al.*, 2009
n-Decylthiotrifluoropropanone	*Bombyx mori* (Bombycidae)	Kong *et al.*,2012
(E,Z)-3,13-octadecadienyl acetate, (Z,Z)-3,13-octadecadienyl acetate	*Synanthedon vespiformis* *Synanthedon pictipes* *Synanthedon hector* (Sesiidae)	Levi-Zada *et al.*, 2011
(E)-11-tetradecenyl acetate, (E,E)-9,11-tetradeca-dienyl acetate, (E)-11-tetradecenol,	*Epiphyas postvittana* (Tortricidae)	El Sayed *et al.*, 2006
(Z)-9-tetradecenyl acetate, (Z)-9-tetradecenol, tetradecyl acetate	*Coryphodema tristis* (Cossidae)	Bouwer *et al.*,2015
(Z,E)-9,12-tetradecadienyl acetate, (Z)-9 tetradecenylacetate, (Z)-11-hexadecenyl acetate, (Z,E)-9,12-tetradecadienol, (Z)-9-tetradecenol, (Z)-11-hexadecenol	*Spodoptera exigua* (Noctuidae)	Acín *et al.*, 2010
(E,E,Z,Z)-4,6,11,13-hexadecatetraenal	*Callosamia promethea* (Saturniidae)	Gago *et al.*,2013
(Z,E)-5,7-dodecadienyl acetate, (Z,E)-5,7 dodecadienol,(Z,E)-5,7-dodecadienyl propionate	*Dendrolimus tabulaeformis* (Lasiocampidae)	Kong *et al.*,2012
(E)-7,9-decadienol, (E)-8-decenol	*Monema flavescens* (Limacodidae)	Shibasaki *et al.*, 2013
ORDER HEMIPTERA		
(4aS,7S,7aR)-nepetalactone, (1R,4aS,7S,7aR)-nepetalactol	*Hyalopterus pruni*, *Brachycaudus helichrysi* (Aphididae)	Symmes *et al.*, 2012
(4,5,5)-(trimethyl-3-methylenecyclopent-1-en-1 yl) methyl acetate	*Delottococcus aberiae* (Pseudococcidae)	Vacas *et al.*, 2019
(1S,4R,10S)-4-(10,50-dimethylhex-40-enyl) 1methylcyclohex-2-en-1-ol	*Oebalus poecilus* (Pentatomidae)	De Oliveira *et al.*, 2013
(3S,6S,7R)-1,10-bisaboladien-3-ol, (3R,6S,7R)-1,10-bisaboladien-3-ol	*Tibracalimbati ventris* (Pentatomidae)	Blassioli-Moraes *et al.*,2020
ORDER BLATTODEA		
(Z,Z)-3,13-dodecadienolide	*Parcoblatta lata* (broad wood cochroach) (Ectobiidae)	Eliyahu *et al.*,2012

ORDER ORTHOPTERA		
(R,R)-(Z)-3,7,11,15-tetramethyl hexadec-2-enal, (R,R)-(E)-3,7,11,15-tetramethyl hexadec-2-enal	*Dociostaurus maroccanus* (Moroccan locust) (Acrididae)	Gago *et al.*, 2013
ORDER DIPTERA		
(-)-δ-heptalactone	*Rhagoletis batava* (Tephritidae)	Büda *et al.*,2020
ORDER HYMENOPTERA		
(-)-iridomyrmecin	*Leptopilina heterotoma* (Figitidae)	Weiss *et al.*,2013

Pheromones in Pest control methods :

Pheromones as insect control specialists vary in five significant ways from insecticides (Table-2). To begin with, pheromones are not poisonous. Rather than changing digestion, neurotransmission or endocrinology, all of which bring about death, releaser pheromones adjust conduct, accordingly altering the likelihood of effective taking care of or reproduction[25]. Second, pheromones are exceptionally species-specific, and accordingly have no impact on non-targets. Third, pheromones are used at lower doses than most insecticides. Sex pheromones are applied to bring down the likelihood of MD at doses of nearly 5-80 g/ha[20], while insecticides can hike to 60-1600 g/ha. Pheromone bait trap insects at applicable doses of 0.1-10 mg/trap, contingent upon the pheromone. Fourth, pheromones are not applied straight, alike insecticides, and are confined in release devices, like rubber septa, wax plates and microcapsules. This implies low exposure of plant material, soil and water by the controlling device. Fifth, the impact of pheromone treatment is slow pace than insecticides. Releaser pheromones uniquely alter the behaviors of pests, rather than enhance the desirable behaviours of beneficial insects[40].

Application methods of pheromones for insect management fall into four groups according to their ultimate effect: 1) mating disruption, 2) monitoring with traps, 3) push-pull strategy and 4) mass trapping. Pest monitoring with pheromone-baited traps allows the early recognition of outbreaks and a more engaged utilization of insecticides[53]. The traps act as explicit and delicate markers with respect to the targeted pest. The advantages include unwanted pesticide treatments, low pest management costs, less pollution and least harm to the environment. The toxic chemical (modest concentration) is applied along with the pheromone to a limited habitat. Individual insects that come into contact with the pheromone dispensers become defiled with the pesticide, which in the end kills them.

Monitoring :

In pest management programmes, monitoring of pestpopulation determines the trend in population aggression[8,18]. Pheromone-based behavioural manipu-lation is one such monitoring tool for many pests[67]. It involves the use of a syn-thetically-derived pheromone formulated into a dispenser aspheromone-trap to selectively attract and intercept the target insect[21]. However, the tech-nique can be modified to meet the requirements of specific agroecosystems. Monitoring systems depend on the connection between trap catches and the pest population or damage instigated by the pest species[10]. The number of male catches gets creates a threshold level in choosing treatment modalities. Sex pheromones are extremely valuable and sensitive for assessing trap catches in finding low insect population levels and are species-specific[32]. Factors including trap design (like color, type, height), type of dispenser, trap location, pheromone purity and dose and environmental conditions for pheromone-baited traps to encourage males pests towards the trapping device[29]. For monitoring, Lepidoptera pheromone traps are now available for a wide range of insect pests (Figure 1). For example, *Plutella xylostella* L. (diamondback moth, Lepidoptera: Yponomeutidae), was more effectively controlled when an insecticide was applied based on pheromone- trap catches compared to a calendar application approach[58]. Monitoring traps can likewise be utilized to foster quantitative relationships between adult capture and injury-causing life phases of a pest. Some common types of pheromone dispensers as of now being used incorporate hollow fibers, impregnated ropes, plastic covers, wax formulations, twist ties, polyethylene vials, sol-gel polymers, and rubber septa[38].

Mating Disruption :

MD is a procedure that depends on the infiltration of the crop with synthetic sex pheromone to dampen substance communi-cation among sexes and, consequently, averting mating[18]. Through MD, male search behaviour is diverted due to competition between synthetic pheromone sources and females, sensory habituation and adaptation of the males, and camouflage of the female plume[67]. Prolonged exposure to a high con-centration of a synthetic pheromone blend may render males insensitive to pheromone plumes of females. In practical circumstances, the mating interruption technique consumes larger quantities of pheromones for proper utilization rather than that utilized for mass-trapping[65]. Therefore, the MD method may be more practical in case of in-expensive pheromones. Synthetic pheromones are generally kept in slow- releasing dispensers capable of releasing pheromone for weeks or even months[47]. Therefore, the application of MD lies in continuous reliable monitoring system for the intended time span. MD in moth works fundamentally through competitive fascination contrasted with the non-competitive mechanisms (camouflage, sensory imbalance and desensiti-zation)[66]. In contrast to traditional insecticide-dependent IPM, MD does not affect non-target organisms and is environmentally benign and approved for biorational and organic production systems[74]. MD has been implemented against multiple lepidopteran pests of field crops, forests, orchards and vineyards. These include the pink bollworm (*Pectinophora gossypiella* Saunders) (Lepidoptera: Gelechiidae), oriental fruit moth (*Grapholita molesta* Busck) (Lepidoptera: Tortricidae)[5].

Push-Pull Strategy :

The push-pull methodology, an alternative to traditional pesticides, synchronously utilized attractant and repellent boost to displease target pests[19]. This technique targets minimum crop injury by adjusting vermin dispersion, utilizing repellent improvements to compel the pest away from the crop, and simultaneously attractant stimuli to 'pull' the pest to different regions out of crop habitat[24]. The advancement of push-pull techniques has been predominantly coordinated to agricultural systems to oversee insecticide obstruction threats or reduce the application of insecticides[6,57]. This technique requires information on chemical ecology, insect biology, and interaction between host plants and natural enemies[55]. Even though there is a large diversity of 'push' and 'pull' elements, such as synthetic repellents, host-derived semiochemicals, host and non-host volatiles, oviposition stimulants, anti-feedants, and oviposition deterrents etc [(50).] The synergistic activity of host plant volatiles and pheromones (Sex and aggregation) attracts the herbivores[49]. In push-pull experiments with aphids; nepetalactone, a aphid sex pheromone component along with (Z)-jasmone (a host-plant volatile product) attracts aphid parasitoids[30].

Mass Trapping :

Mass trapping is an immediate control procedure that utilizes an enormous number of pheromone traps to diminish the population density of the target species and/or pest[17]. Compared with MD, mass trapping is more productive when both control techniques have an equivalent number of pheromone sources. Mass trapping has been especially effective in controlling large weevils in tropical crops, for example, palmito palms, oil palms, plantains, and bananas[45]. The most widespread use of pheromones in storehouse against Lepidoptera are female-released sex pheromones that allure only males[1]. Hence, any endeavour to restrain the population by mass-trapping would require an adequate number of trapped males so that almost all females remain unmated. Hypothetical contemplations of mass-trapped males consider the density of males in the population and the potential number of mating that a male can make in its life span. It is usually more effective against isolated pest populations and occur at low-density[27]. Some other key factors involved in the successful implementation of mass trapping include the optimization of lures and traps so that the target pest population is reduced below the threshold for economic injury[28]. Pests of field crops, orchards, and forestry in the orders Lepidoptera, Diptera, Coleoptera, and Homoptera have been targeted using the mass trapping[37]. The effectiveness of mass-trapping, and other pest control techniques, heightened the method applied to combat *Ephestiakueh niella* infestations using traditional IPM. Pheromone funnel-traps loaded with 2 mg of (*Z,E*)-9,12-tetradecadienyl acetate (ZETA) pulled a 54,170 number males[68]. The endless existence of the traps caused a noticeable reduction of *Ephestiakueh niella* populations. Results showed that the moth population density successfully decreased and kept up with at a low level through mass-trapping associated with localized insecticide treatments, and careful cleaning of equipment and various mill *areas*[33].

Table-2. Insect Sex Pheromones vs. Conventional Pesticides in Pest Control[13]

Pheromones	Pesticides
Biological equilibrium of nature is not disturbed (partial repression)	Upsets the biological equilibrium of nature (elimination of most of the insects)
Repression of insect pest(Selective)	Destruction of insects(Nonselective)
Nonpolluting	Causes wide-ranging environmental pollution
Nontoxic	Toxic to different animals and humans
Decompose in the field(Unstable)	Some products are exceedingly stable
Quantities required are minute (dose needed to attract alone insect)	Vast quantities required (it takes about 10–6 g to destroy a single insect)
Affordable, easy to install and manage	Expensive to buy, time-consuming, labor –intensive to apply
Pheromones as needed into the air as an aerosol spray. It is not sprayed directly on the crop	Pesticide is applied directly to a target pest (plant or animal) the whole site is affected including crop plants

Insecticides vs. Pheromones :

Insecticides do not attain a long-term pest population decrement. Insecticide overuse also induces outbreaks of secondary pests[71]. In orchards and vineyards, pheromone treatments substituted insecticide spray against phytophagous mites. Pheromone treatment was cost-effective also[36]. Pheromone-based methods produce better results in the long run, due to recovery of the beneficial fauna (Table 2)[38]. Insects with hidden, protected lifestyles, including those with woodboring or underground larval habits, cannot easily be controlled with cover sprays of insecticides. Here, control with pheromones is advantageous, since it aims at the mobile adult life stage, and functions to prevent oviposition altogether[4].

The inordinate utilization of synthetic chemical insecticides causes pollution, resistance issues and pest resurgence. Sex pheromones are normal insect behavior controllers that fill in as reasonable chemical agents in sustainable agriculture. Pheromones and other conduct modifying semiochemicals are currently a necessary piece of various pest management programs and are relied upon to assume a significant role in high-tech crop protection of the future. These will help give a sustainable environment, substituting the wide range insecticides, as monitoring or management tools of IPM. Control of some economically significant insect species by mass-trapping might be conceivable in specific conditions, whenever coordinated on an area wide premise. This is on the assumption that labour costs are low, that the traps are cheap and simple to operate and that the farmers cooperation can be achieved. Such chemico-ecological methodology would exploit normal controlling strategies and may fit well with existing cultivating rehearses. According to the molecular point of view, huge examination is being performed on the revelation of new pheromone- binding proteins, sensory- binding proteins and chemical signal transduction mechanisms associated with sex pheromone communication. Advances in genomics, sequence advances, and transcriptomics of insect olfactory framework will assist with growing new advances for more sustainable pest management techniques, consequently diminishing the utilization of synthetic insecticides. Research need to be done on pheromone-based pest management to make them cost-effective and more market available.

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