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ECO-FRIENDLY MANAGEMENT OF INSECT PESTS IN AGRICULTURE BY PHEROMONES: A REVIEW

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ABSTRACT

Insect pest poses a major threat to agricultural commodities and profitable crop production. To overcome the pest problem, farmers use different kinds of chemical pesticides, that generate negative impacts on the environment and human health. Usage of pheromones to control insect pest provide numerous benefits. Pheromone is a semiochemical produced and used by insects for communication. Different insect species biosynthesize pheromones in various sites of their body using different pathways, i.e., female moth uses mono- or poly-olefinicacetates, alcohols, or aldehydes compounds, whereas male moth uses aromatic compounds, mostly to attract their counterpart. These pheromones are biosynthesized in the modified epidermal cells through the modified fatty acid biosynthetic pathways. On the other hand, bark beetles produce terpenes, alcohols, or bicyclic ketals in their oenocytic cells, which act as a signal for gathering other members. The ways of chemical communication can be used to direct the agronomical harmful pests into the trap, which subsequently limits damage of crops by them. Pheromone traps provide various useful applications like monitoring the presence of any exotic-pests, trapping out specific pests, disrupt their mating, or even combine the application with insecticides. Several environmental factors like rainfall, temperature, wind speed, and non-environmental factors including the size of the pest population, and presence of migratory pests affect the effectiveness of pheromone traps. However, usage of pheromone provides an eco-friendly and biorational way of controlling the pest in agriculture, which out weight the harmful effects of chemical pesticides. This review discusses various classes of pheromones and their usage in eco-friendly management of insect pests.

Keywords: Pheromone, ecofriendly agriculture, pheromone traps, eco-chemicals, insect pest

Introduction

Insects are the major concern of agricultural production loss. Records show that 50% of production loss in cotton, 35% in oilseeds, 25% in rice, 30% in pulses, 20% in sugar cane, and 5-10% in wheat are caused by pests (Rai and Ingle 2012). While more than 1000 species of insects are responsible for the global production loss, only less than 10 percent of them are considered as the major (Dhaliwal *et al.* 2010). To get rid of these pests, farmers tend to use chemical insecticides. Although this kind of practice provides a temporary solution to the problem, it rises much more issues further. Insecticides cause oxidative stress which exerts harmful effects on both humans and other organisms. Nearly 300,000 deaths are caused worldwide every year by poisoning from pesticides (Sabarwal *et al.* 2018). Moreover, insects sometimes grow resistant to pesticides if they are used frequently. For example, the diamondback moth, *Plutella xylostella* which attacks crucifer vegetables worldwide, becomes resistant to all classes of insecticides used against it in south-east Asian countries (Dhaliwal *et al.* 2010). Considering these and other associated drawbacks with the usages of insecticides, scientists around the world tried to get to the bottom of this issue in an eco-friendly way. Usage of pheromone to control pests in agricultural lands proves as a useful solution in this regard. Pheromones are chemical signals used by an organism to induce a behavioral or physiological response in another individual of the same or different species (Symonds and Elgar 2008). These semiochemicals carry out a wide range of functions in insects for instance attracting potential mates, warning other members from danger, communicating with individuals and others (Wyatt 2003). Such chemical signal can be used to lure insects and contained in a certain place so that they cannot do any harm to the crops (Mullen 1992). Usage of this pheromone trap can lower the costs and production loss, therefore boost the profits in agriculture (Yang *et*

al. 2009). Besides, the pheromone trap is eco-friendly, creates no harmful effects on other organisms besides the targeted one (Lucchi *et al.* 2018). Due to the advantages, the market for agricultural pheromone is rocketing day by day and is estimated to reach a value of USD 5.7 billion by 2025 (PRNewswire 2019).

A large body of literature is available on various kinds of insect pheromones and the potentials for eco-friendly management of insect pests in agriculture (Bestmann and Vostrowsky 1979, Yan *et al.* 2021). The challenges and prospects of sex pheromone aerosol devices for mating disruption of insect pests have recently been reviewed (Benelli *et al.* 2019) This review updates knowledge and understanding about various classes of pheromones and their usage in eco-friendly management of insect pests for promoting sustainable agriculture.

Review Methodology

This study is based on the systematic and non-exhaustive literature survey for related published research articles, papers, and books concerning insect pheromones and their application in eco-friendly management of insect pests in agriculture. A comprehensive literature bank (including both online and offline information) was collected by web-surfing as well as comprehending printed materials for identifying the research questions and knowledge gap with respect to various classes of insect pheromones and their practical application in eco-friendly management of important insect pest. The review process involved the selection of thematic areas and narrowing down to well-suited keywords to extract contemporary information. For online materials, the popular academic search engines viz. Google Scholar, PubMed, ScienceDirect, Scopus, ResearchGate, Springer, as well as official websites were explored with selected keywords. The used keywords include "insect pheromones", "pheromones and semiochemicals", "classes of pheromones", "pheromones in agriculture", "pheromones in insect control", "chemistry of pheromones", "eco-friendly management of insects by pheromones", "pheromone trap", "pheromones in insect control in Bangladesh" and "use of pheromones in crop protection". At first, the abstract and major findings of secondary materials were critically overviewed to assess the relevancy to be included in the current study. Later on, the eligible materials were sorted (e.g., abstracts, full text, and salient findings) based on the research frame of the study. No specific timeline or verified methodology (e.g., PRISMA) was applied during selection and reviewing the information source. However, the screened references were scrutinized and summarized to build-up the story focusing on the presence of pheromones in eco-friendly management of insect pests. Finally, the research gap regarding the studied area and potential steps for effective application of pheromones in biorational management of insect pests for the promotion of sustainable agriculture are suggested through rational exposition.

Various classes of insect pheromones

Pheromones are primarily categorized into three classes viz. releaser pheromones, primer pheromones and imprinting pheromones. Releaser pheromones have an immediate and reversible response directly operated through the central nervous system, e.g. recognition, or through rapidly active neurohumoral channels, as exemplified by the milk-ejection reflex (Cross and Harris 1952). The primer pheromones have the exteroceptive response implicating the anterior pituitary gland**.** They make the development slow, demanding a prolonged stimulation, which consequently initiates a chain of physiological effects in the body of the recipient. The imprinting pheromones cause stimulation at a critical period of development, which may cause a permanent modification to the behavior of adults.

Diversity in pheromones

The chemical composition of pheromones is highly species-specific and varies enormously among species (Symonds and Elgar 2008). For example, sex pheromones produced from female Lepidoptera are mono- or poly-olefinicacetates, alcohols, or aldehydes whereas pheromones produced by male butterflies as well as moths are aromatic compounds (such as benzyl alcohol, phenylacetaldehyde) and aggregation pheromone produced by bark beetles are mainly terpene alcohols and bicyclic ketals (Bestmann and Vostrowsky 1981). Therefore, to understand pheromones' chemical structure and role, they can be divided into some categories as discussed in below.

Pheromones of butterflies and moths

Pheromone production is observed in both males as well as females of different species of butterflies and moths (Roelofs and Comeau, 1970, Leyrer and Monroe 1973). The sole purpose of those pheromones is either to attract the different sex for mating or to inhibit or disrupt

the sexual activity (Wakamura 1978, Kaae *et al.* 1972, Smith *et al.* 1974). Sex-attracting pheromones produced in Lepidoptera can only be detected by males. Female, on the contrast, generally shows no sign of behavioral response unless they are available in high concentration (Priesner *et al.* 1975, Priesner *et al.* 1977, Bestmann 1976). Throughout the species, female butterflies and moths produced a wide range of pheromones compared to their counterparts. According to the chemical structure of the pheromone they produced, sex-attracting pheromone in female butterflies and moths can be classified into monounsaturated acetates, polyunsaturated acetates, monounsaturated alcohols, and polyunsaturated alcohols (Bestmann and Vostrowsky 1981).

In the case of monounsaturated acetates, sex pheromone produced by female Lepidoptera are a different variant of decent acetate (Inscoe *et al.* 1976). Such as Z-5-Decenyl acetate acts as a sexual attractant for *Agrotis fucosa* species (Wakamura 1978), E-5-decenyl acetate for *Anarsia lineatella* (Roelofs *et al.* 1975). Same monounsaturated acetates pheromone may act as a sex attractant for one species but disruptant or inhibitor for other species. As an example, Z-7-dodecyl acetate which acts as sex attractant in *Agrotis ypsilon* (Hill *et al.* 1979), disrupts a sex attraction in *A. californica* (Chisholm *et al.* 1979) and inhibit in *Rhyacionia buoliana* (Smith *et al.* 1974).

Polyunsaturated acetates of pheromones in butterflies and moths contain a long chain of unsaturated acetate chain starting from dodecadienyl acetate to octadecadienyl acetate which varies among species. Like, monounsaturated acetate, some of the polyunsaturated acetates also act as inhibitors, sex attractant disruptors while most of them act as a sex attractant. Some examples of polyunsaturated acetates of pheromones included E-7, Z-9-dodecadienyl acetate as a sex attractant in *Lobesia botrana* (Roelofs *et al.* 1973), Z-9, E-12-tetradecadienyl acetate as a sex attractant in many species like *Anagasta kuehniella* (Kuwahara *et al.* 1971), *Ephestia elutella,* while sex attractant inhibitors in *Cadra cautella* and disruptant in *Plodia interpunctuella*, Z-11-hexadecadienyl acetate as a sex attractant in *Eudia pavonia* (Sower *et al.* 1973),

For the monounsaturated alcohols category, several variants of decen-1-ol to hexadecen-1-ol can be observed throughout the species of female butterflies and moths (Roelofs *et al.* 1975) (Ando *et al.* 1977). Z-7-dodecen-1-ol, a monounsaturated alcohol pheromone acts as a sex attractant in a wide range of species including *Protobathra leucostola* Meyrick (Ando *et al.* 1977) whereas for some species like *Pseudoplusia includes* acts as inhibitors (McLaughlin *et al.* 1974).

Different variants in the long chain of polyunsaturated alcohols, ranging from dodecadien-l-ol to octadecadien-l-ol was witnessed (Nielsen *et al.* 1978). Z-9, E-12-tetradecadien-l-ol, an example of polyunsaturated alcohol found in some species which acts as sex pheromone in *Plodia interpunctuella* (Sower *et al.* 1973) while inhibitor in *Cadra cautella* (Sower *et al.* 1974).

Male counterparts of Lepidoptera also produce different pheromones which are aromatic. Unlike pheromone produced in female Lepidoptera, they play roles only as sex pheromone and in aphrodisiacum (Bestmann and Vostrowsky 1981). Some species of male Lepidoptera such as *Apamea monoglypha, Mamestra brassicae* use benzaldehyde and benzyl alcohol as a pheromone to attract the opposite gender for mating (Aplin and Birch 1968, Bestmann *et al.* 1976).

Bark beetle pheromones

Bark beetles generally produced aggregation pheromones, which are mainly terpene, alcohols, and bicyclic ketals (Bestmann and Vostrowsky 1981). They are not only affected by the semiochemicals produced in the male or female bark beetles but also pheromones that are produced in the host cell and other insects (Vite *et al.* 1972, McNew 1970, Pitman *et al.* 1969, Vite and Renwick 1971). Male-produced pheromones mostly act as aggregation pheromone and affect largely on *Ips*, Dendroctonus genre (Bestmann and Vostrowsky 1981). For example, alcoholic pheromone compound, 2-methyl-6-methylene-2, 7-octadien-4-ol produced in male bark beetles acts as aggregation pheromone in different species of *Ips* genre including *Ips accumulates, I. avulvus, I. bonanseai, I. cribricollis* (Vite *et al.* 1972). Female bark beetles also produce different pheromone substances which act mostly in aggregation while some are aggregation inhibitors and synergists (Bestmann and Vostrowsky 1981**).** For example, Female produced aggregation pheromone compound 2-pine-4-ol or trans-verbenol, affect several species of *Dendroctonus* genre including *D. brevicomis, D. frontalis, D. jeffreyi, D. ponderosa, D. pseudotsugae* (Pitman *et al.* 1969). On the other hand, these beetles are sometimes affected by a pheromone produced in other insect species. Such as 3-methyl-3-cyclohexen-l-ol produced in another kind of insect acts on *D. pseudotsugae,* fir beetles. They

are also affected by a pheromone produced in the host cell. For instance, 2,6,6-trimethylbicyclo [3.1.l]-hept-2-ene-α-pinene produced in cannabis, has synergistic effects on *D. frontalis* and *D. ponderosae* (Renwick and Vite 1970).

Pheromones of other beetle family

Other beetle's family besides bark beetles also use different chemical compounds as a pheromone for maintaining sexual attraction, sexual attraction disruptant, and other purposes (Bestmann and Vostrowsky 1981). Female *Limonius californicus* produces valeric acid which acts as an attractant for other members of that species (Jacobson *et al.* 1973).

Pheromones of true bugs (Heteroptera)

True bugs are affected by alkyl aldehydes and fatty acids. As two alkyl aldehydes E-2-hexanal and E-2-octenal are used as alarm pheromone in *Cimex lectularius* (Levinson *et al.* 1974). In case of fatty acids, ethyl acrylate, hexyl butyrate, and E-2-hexenyl butyrate were found to affect sex pheromone in *E. integriceps*, *Lygus linolearis*, and *L. linolearis* bugs respectively (Vrkoc *et al*. 1977, Gueldner and Parrott 1978).

Site of pheromone biosynthesis in insect

As variation can be seen in pheromone structures among different insect species, their site for biosynthesis also differs (Vander *et al.* 2019, Quennedy 1998 Ma and Ramaswamy 2003). Some insect species modified epidermal cells which are situated in the abdominal segments while for some other species special glands are in use (Ma and Ramaswamy 2003, Hallberg and Subchev 1996). After being produced, those semiochemicals are then throughout the body and picked up by the pheromone glands and ducts for effective release (Schal *et al.* 1998).

Gland act as a site for oxygenated pheromone components in a variety of moths (Bjostad *et al.* 1987, Jurenka 2003, Rafaeli and Jurenka 2003). This gland is modified epidermal cells located within the 8th and 9th abdominal segments (Ma and Ramaswamy 2003) although for some species like *Theresimima ampelophaga* (Zygaenidae) this is located on the dorsal part of the third to fifth abdominal segments (Hallberg and Subchev 1996). Another group of cells that is associated with the pheromone synthesis in moths are oenocytes which are linked with the epidermal cells throughout the abdomen (Wigglesworth 1970). After being produced these pheromones are then transported throughout the insect body with the help of lipophorin. Finally, they are taken up by the pheromone gland for release (Schal *et al.* 1998).

Although the site for pheromone biosynthesis varies in the case of Coleoptera, it is usually done in the defined gland located in the abdomen of the insect body (Nardi *et al.* 1996). This kind of gland is modified oenocyte cells that are connected to the tracheal system through ducts. Pheromone is released from the insect body later on from those tracheal systems. For bark beetles, these sites are known as mid guts. They use these cells for both food digestion and pheromone production. Produced pheromone is then secreted into the gut lumen and released along with the frass (Hall *et al.* 2002).

For flies and cockroaches, the biosynthesized site of pheromone is also similar to those moths. Here also, the oenocyte cells are in action for pheromone production and lipophorin transported them throughout the body. The produced pheromone is then released from the cuticular surface of the insects (Gu *et al.* 1995 and Schal *et al.* 2001).

Biosynthetic pathways of pheromones

Pheromone biosynthesis in moths

As moth-produced pheromones have a straight-chain carbon backbone, it is assumed that these compounds are synthesized inside the insect body through modified fatty acid biosynthetic pathway. Several enzymes like acetyl-CoA carboxylase and fatty acid synthetase are associated with this process which produces type-1 oxygenated compounds to produce this carbon chain. This chain is further modified in several ways like introducing a double bond by desaturates and production of short length chain by specific b-oxidation enzymes. Later on, enzymes like oxidases, reductases, and acetyltransferases modify the oxygenated functional groups and produce specific pheromone blends for each species.

In the first stage, saturated fatty acids are produced from Type 1 compounds with the presence of acetyl-CoA carboxylase and fatty acid synthetase enzyme. Then in the second stage, monosaturated fatty acids are formed from those saturated fatty acids and limited chain shortening occurs which produces some compounds that are reduced

to alcohol by reductase. Finally, aldehyde and acetate ester pheromones are produced from this alcohol by the action of oxidase and acetyl-transferase, respectively (Bjostad and Roelofs 1984, Jurenka *et al.* 1994, Tang *et al.* 1989).

Pheromone biosynthesis in bark beetles

The biosynthesis process of bark beetles includes fatty acid, amino acid, or isoprenoid types of pathways. Although in some cases beetles converted their dietary host compound into pheromone, most of the time they synthesized it in *de novo* (Seybold and Tittiger 2003, Seybold and Vanderwel 2003).

Isoprenoid-derived pheromones are utilized primarily in the bark beetles (Schlyter and Birgersson 1999, Seybold *et al.* 2000). They use enzymes like HMG-CoA synthase and HMG-CoA reductase in the early stage of the pheromone biosynthesis pathway which produces mevalonate. Later on, this mevalonate is used as a substrate and geranyl diphosphate is formed by the action of an enzyme called geranyl diphosphate synthase in the last stage. Some bark beetles use a bit different pathway than this one. This kind of species utilizes pyruvate and glyceraldehyde 3-phosphate to produce 1-deoxy-xylulose 5-phosphate and finally convert them into isopentenyl diphosphate (Rohmer 1999).

Pheromone biosynthesis in other beetles

Pheromone modified via fatty acid biosynthetic pathways can be utilized by some beetle species. Several beetle species use longer chain-length methyl-branched pheromone components for communication (Bartelt *et al.* 1992). These branched hydrocarbons comprise 10-12 carbons that have double bonds and methyl along with ethyl branches. To produce these methyl and ethyl branches beetles use propionate and butyrate (Bartelt and Weisleder 1996 and Petroski *et al.* 1994). During the elongation process, produced enoyl-ACP intermediate is not reduced due to the inactivity of the enoyl-ACP reductase enzyme which makes the nature of these hydrocarbon desaturated (Petroski *et al.* 1994).

Pheromones application in insect pest control

For effective and practical use of pheromone for managing pests, the specific chemicals first need to be isolated, identified, and synthetically produced. Some examples of commercially available pheromones' chemical structures are shown in figure 1 while their trademark, producing organism, and behavior are mentioned in Table 1. After following those steps that synthetic pheromone which is a copy of the host-produced pheromone, can be used in four ways. First of all, it can be used in traps as a lure to monitor the pest population. Secondly, it can also be used and designed to trap out a pest population. Thirdly,

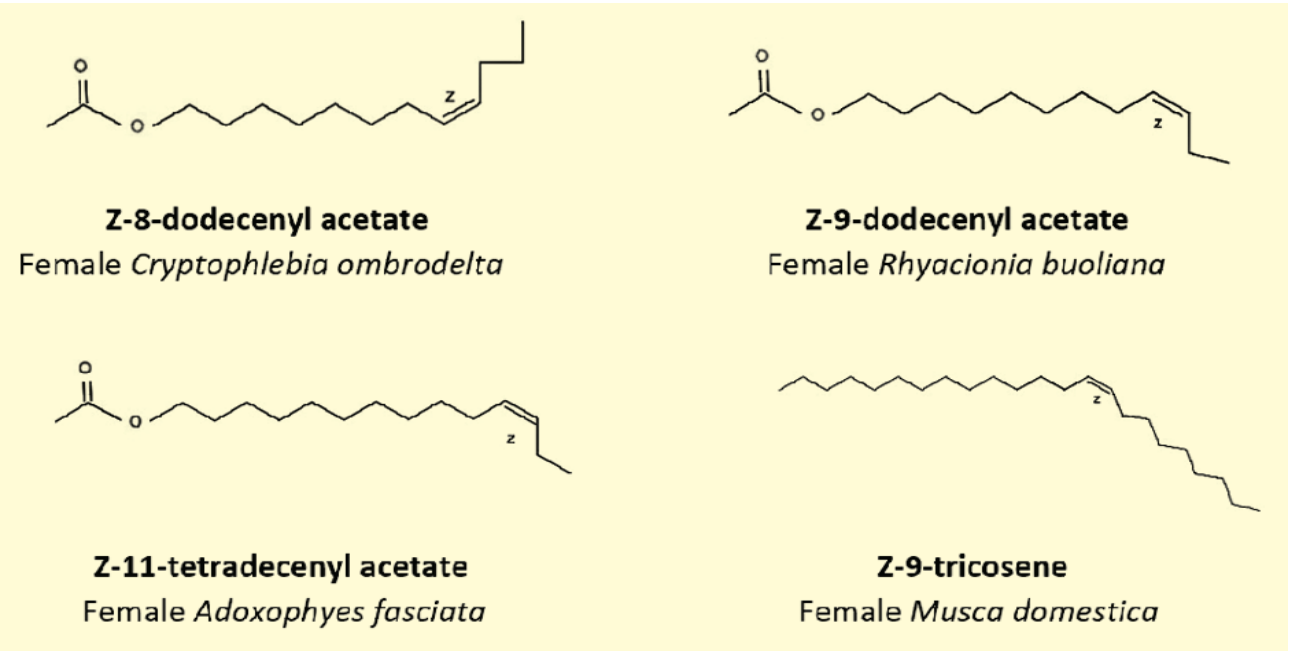


Figure 1. Chemical structures of some commercially available pheromones.

Table 1. Some commercially available pheromones, their trademark along with the organisms produce them and their behavior.

Name	Trade mark	Sex	Affected insect species	Behavior	Ref
Z-8-dodecenyl acetate	orframone®, funemone®	female	*Cryptophlebia ombrodelta, G. molesta, Hedianubiferana*	sexatt, sexatt disrupt, inhib	(Ando *et al.*, 1975) (Gentry *et al.*, 1978) (Arn *et al.,* 1974)
Z-9-dodecenyl acetate	grapemone®	female	*Cosmopterix spec., Paralobesiaviteana, Rhyacionia buoliana*	sexatt, sexatt disrupt, inhib	(Ando *et al.*, 1975) (Roelofs *et al.*, 1971) (Smith *et al.*, 1974)
Z-11-tetradecenyl acetate	redlamone®	female	*Adoxophyes fasciata, Archips argyrospilus, Argyrotaenia citrana*	Sexatt, sexattinhib, synerg	(Tamaki *et al.*, 1971) (Roelofs *et al.*, 1974) (Hill *et al.*, 1975)
Z-9-tricosene	muscamone®	female	*Musca domestica*	sexatt	(Carlson *et al.*, 1971)

for disrupting insect mating, they can be utilized. Finally, this synthetic pheromone can act as an attractant in an insecticide-containing bait (Weinzierl *et al.* 2005). Some examples of commercially available attractant baited traps across the globe include wing trap, water-pan trap, delta trap, heliothis trap, pherocon II trap, and funnel trap (Figure 2) (Hagstrum *et al.* 2012). However, in Bangladesh, lure spectrum, water traps, buckets traps, net traps, bucket with window traps, delta traps, yellow sticky traps, and wing traps are mostly in practice (Figure 3) (Islam 2012).

Pheromones application in monitoring insect population

To capture and then monitor the insect population, an adhesive-coated surface or a funnel-shaped entrance is used for constructing this kind of trap. Inside the trap, a lure is placed which is mostly made of paper or plastic. The lure is soaked or covered into the chemical attractant for target pest species in such a way that the active component is released for several days or weeks.

Attractant baited traps are very sensitive and effective. They can capture insect which is present in very low density. These traps can also be used to detect the presence of exotic or new kinds of the pest as well as to determine the relative density of the pest population. However, these traps have some major drawbacks. Several environmental factors like temperature, wind speed, rainfall, affect the performance of these traps. The crops are damaged by both mature and immature pests but attractant baited traps can capture only mature pests which is another major

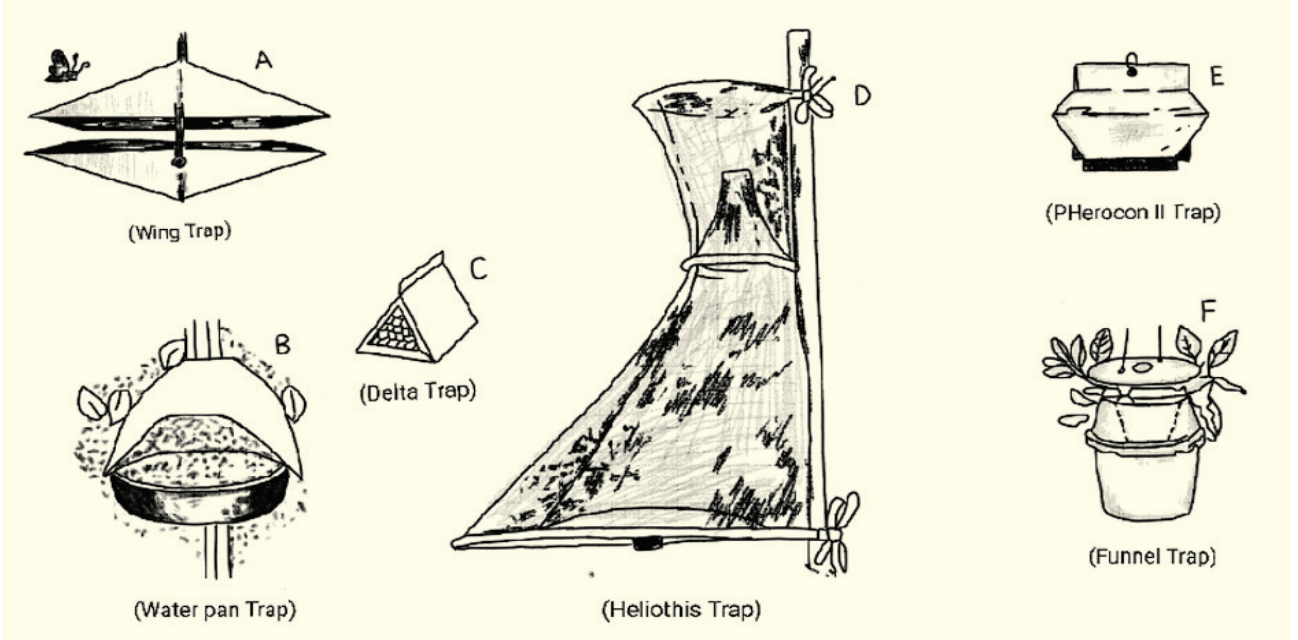


Figure 2. Commercially available pheromone traps across the globe.

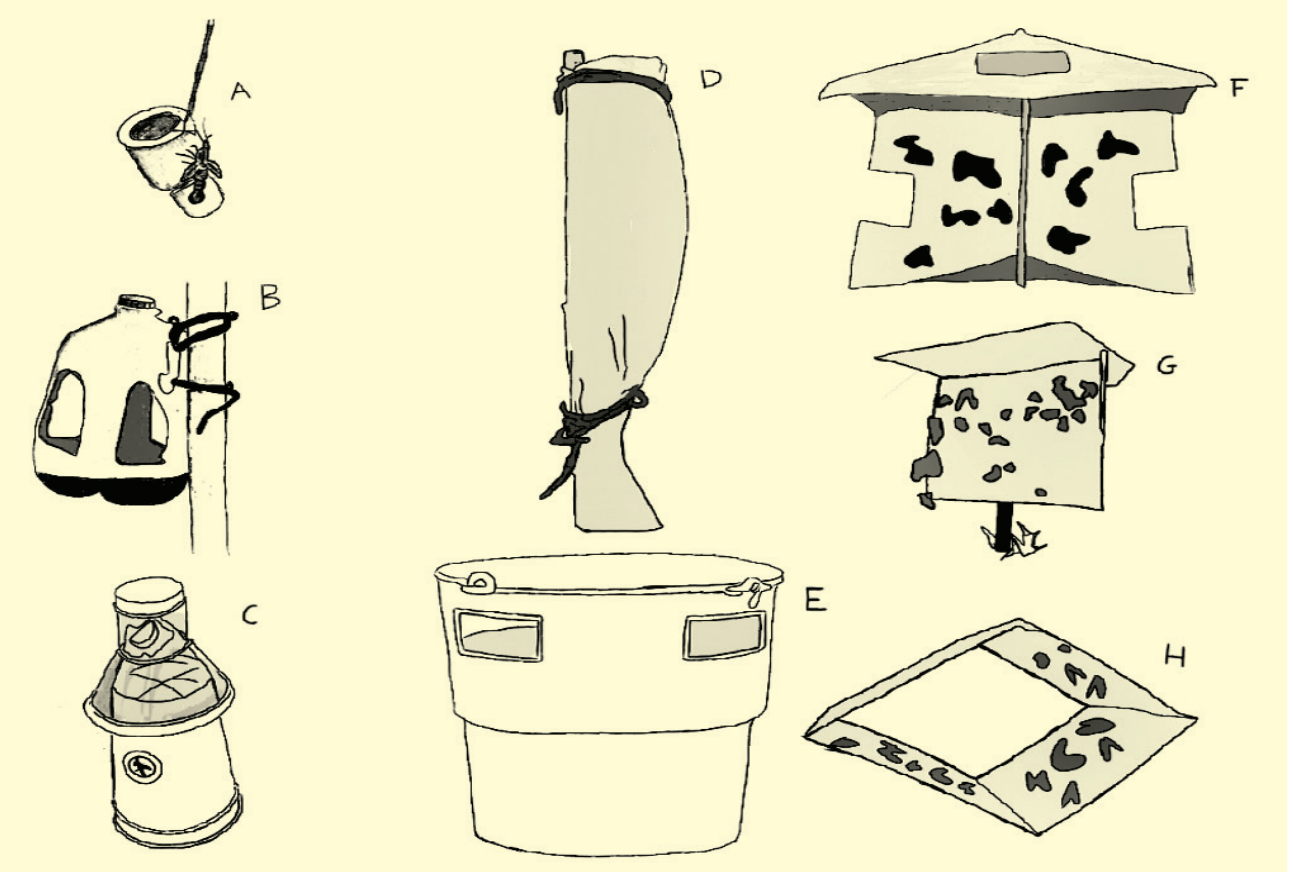


Figure 3. Commercially used pheromone traps in Bangladesh. (A) Lure spectum; (B) Water Trap; (C) Bucket Trap; (D) Net Trap; (E) Bucket with window Trap; (F) Delta Trap; (G) Yellow sticky Trap; (H) Wing Trap.

drawback. Despite the drawbacks, these traps prove as a useful, efficient, and labor-saving method for monitoring pests in agriculture (Curran *et al.* 1989).

Pheromones in trapping out pest populations

To reduce the local population of insects and the damage they cause, ample pheromone traps can be placed throughout the pest environment. This mass trapping effort subsequently traps out target insect species and limits their population for that certain area. Pheromone trap is proved very useful to trap out a range of important pests such as bark beetles, codling moths, apple maggot, Japanese beetle, and Indian meal moth (Birch and Haynes 1982). For trapping out different insects, various types of pheromone are used. Aggregation pheromones, on one hand, are used to trap out beetles. As this kind of pheromone attracts both male and female beetles, mass trapping can decrease the beetles' population significantly. On another hand, for several species like moths, sex-specific pheromones are used. Pheromone produced by female or male moths can be used to make lures which in turn attract and trap out the opposite sex. This significantly reduced the chance of successful mating and therefore limit the pest reproduction and population. However, the success of this kind of trap depends on whether male or female insects are captured before or after the mating occurs. Another potential problem relating to this kind of trap is the efficiency relies on the size of the population of pest species. If the size of the pest population is high, even after placing a large number of traps, some male moths will be able to locate and mate with the female. Consequently, mated females produce a large number of fertile eggs and maintain the size of the population. Despite the issues, this kind of trap can work ineffective way to reduce pest population where the initial population size is smaller and insects are trapped before mating occurs (Curran *et al.* 1989).

Pheromone application in disrupting insect mating

Insect mating can be disrupted by broadcasting sex attractant pheromone over an area. In this approach, male insects that rely on chemical attractants to find female insects for mating are unable to do so because an artificial pheromone signal drives them to a frustrating destination, or due to the constant exposure of the pheromone they cannot detect additional pheromone message. Artificial attractants here outcompete the natural pheromone produced by female insects. In field, the pheromone is applied in hollow plastic fibers, capsule-like pellets, and attractant-impregnated plastic strings or ties for this purpose. Trials of this kind of usage of pheromone have been successful against several potential insects such as the oriental fruit moth, pink bollworm in cotton, grape berry worm, tomato pinworm, and several pests of forest conifers. Likewise, the previous trapping out method, this kind of practice is also affected by the population size. This kind of practice is efficient only when the pest population is not high and the targeted area is isolated from the source of migratory pests (Roelofs 1979).

Application of pheromones in combination with insecticides

Pheromone can be used with insecticide. In such practice, the pheromone is used to lure insects into the bait where toxic insecticide is applied. This method is effective even in low rates of insecticides. It also provides an eco-friendly way of using insecticides as this practice leaves no residues in plants or animals. Currently, it is used to control a plethora of pests including house fly, slugs, certain ants, cockroaches, and yellow jackets (Showers *et al.* 1989).

Advantages and challenges in pheromone-based insect control

Many benefits of pheromone-based insect control programs common to other biological-based management methods, including there are almost no remnants available for certain delivery system, they have ignored health risks, rapid registration process, and no accumulation in wildlife or ground water. Additional benefits include reduced employee re-entry or harvest times and limited effects on other management methods, such as irrigation planning. Pheromone-based hybridization has also been identified as a strong management tool for decrement pesticide resistance. While resistance to pheromones used in wide areas can be expected, there is only one case written down for resistance, in which an incomplete pheromone combination is added against a tea tortrix in Japan. However, the preparation of the mixture removed the problem (Mochizuki *et al.* 2002). The main advantage of pheromone-based systems is that they are highly selective. Often, only the main target species respond to the pheromones, with non-targeted effects on organic control agents within the field or outside the cropping system. The use of pheromones against primary pests does not lead to secondary pest or pest regeneration, which creates opportunities for biological control of other species of insects. However, a high level of selection can also be a major barrier to heavy use, in cases where secondary pests become a problem as pesticides are eliminated. Applications for pesticides that are important to the pests are sometimes indirectly controlling other pests as a benefit of catching. For example, outbreaks of leaf dealers (such as *Pandemic pyrusana*) have been reported in California. Similar effects have been observed in apple orchards under various systems using the disruption of codling moth interactions (Nicholas *et al.* 1999), during the removal of organophosphorous pesticides (OP) azinphos-methyl, the number of wooly aphids (*Eriosoma lanigerum*), a brown apple (*Epiphyas postvittana*), a San Jose scale (*Quadraspidiotus perniciosus*) and budworm (*Helicoverpa* spp.) have increased. Other possible limitations include: (1) the lack of an identified pheromone for certain insect species; (2) high production and production costs; (3) production strategy requirements or special equipment; and (4) the need to increase the pheromone system in high levels of pest suppression. Pheromone systems work best with low to moderate populations, and high-pressure situations where injuries from previous years exceed 1 to 2% often require pesticide applications to prevent commercial damage. Therapeutic parameters have been developed using modified pheromones, but they vary between plants and regions. Fertilizer interference, like other pest control strategies, needs to be considered within the context of a complete pest control system rather than a standalone system. Monitoring the intended problem with pheromone traps can also be a problem, as the pheromones used to disrupt the mating process will prevent the moths from finding traps. Even in the general field, pheromone traps are rarely used as a single indicator of insect problems; instead, they are often used in combination with other methods, such as direct injury tests. The use of large-scale barriers that still attract other moths even under mating

interference is useful in tracking specific insect aircraft (such as codling bottles) or as a risk assessment tool. Other species, such as the Oriental fruit culture (*Cydia molesta*), do not show this answer. However, it is possible to develop a non-oral attraction used for mating disorders (Light *et al.* 2001).

Present status of pheromone use in Bangladesh

Lots of evidence suggest that synthetic insecticide uses are increasing in our country dramatically. Farmers get the pesticides easily in the market and they use those frequently in their crop field regardless of the necessity, which is affecting our environment and ecosystem adversely. Nowadays, Government is becoming aware of the negative environmental and health aspects concerned with the use of these compounds. Therefor, it is an urgent need for the development of alternative pest control technologies (Islam 2012).

Bangladesh Agricultural Research Institute (BARI) and Department of Agriculture Extension (DAE) provided synthetic sex pheromones and beneficial insects to many farmers in some districts renowned for growing vegetables like Jessore, Narsingdi, Comilla, Bogra, Pabna, and other 244 Upazilas experiment. They find out whether these inputs could replace harmful pesticides to reduce damage to public health, as well as harmful pests, and can be controlled by using sex pheromone traps, locally known as magic trap. This technology is popular among a little number of farmers due to the minimal availability and research of pheromones, the knowledge and availabilities of pheromone in Bangladesh-related information were reported by (Islam 2012). However, the popularity of pheromone uses in management of insect pest such as eggplant shoot and fruit borer, *Leucinodes orbonalis* in Bangladesh is increasing day by day (Nahar *et al.* 2020).

Scientists from various organizations (such as Natural Resources Institute, NRI; Bangladesh Rice Research Institute, BRRI, and the multinational agrochemical company Syngenta) are working to find out a sustainable method for controlling insects by pheromone lure associated sleeve traps which are both effective and cost-efficient in the insect-pest control that are responsible for more or less 70-80% of pest damage to the rice crops. However, a all these things good news for us is that the pheromone of fruit and shoot borer moth is now synthesized and being produced in the factory. It is now available in the market and, however, one needs two items to use the sex pheromone in the field: the chemical (or the pheromone) lure and a suitable trap, which are easily available in Bangladesh with much cost-effective price. However, there are some broad problems or challenges identified in using pheromones for insect control in Bangladesh. These challenges or problems include (i) lack of enough study and research on pheromones in Bangladesh; (ii) insufficient materials for the pheromone technology; (iii) inadequate training programs for inspiring the farmers about the knowledge of pheromone technology; and (iv) limited commercial manufacture of pheromone technologies.

Prospects of pheromones application in agriculture in Bangladesh

A growing public concern over potential health hazards of synthetic pesticides and the steep increase in cultivation cost, making a low profit by farmers have consequently led to an exploration of eco-friendly pest management tactics like ICM (Integrated Crop Management). Considering the scarcity of sex pheromones as well as beneficial insects, the researchers have opined that the use of a higher doses of pesticides has destroyed our biodiversity. The Government is yet to give consent to the bulk import and mass use of insect pheromones. It is expected that the government and many private sector entrepreneurs are to set up more laboratories to identify and synthesize pheromones of harmful insects for the development of a sustainable pest management system (Islam 2012). To overcome the limitations related to pheromone technology for pest management; the government, NGOs, and personnel engaged in agro-research works should be concern about the following recommendations:

1. The investment should be raised in the pheromone research works collaborating with various agro-based research institutes and agricultural universities as well.
2. The establishment of a new institution/ foundation is highly recommended to meet up the need for establishing pheromone techniques and their adaptation in Bangladesh agriculture.
3. The Government might also encourage the development of farmer's cooperatives to ensure the availability of pheromones at the right time.

4. The fund should also be raised to help to generate a pheromone-based technology associated with climate change hazards and to disseminate such technologies at the farmers' level.
5. Researchers should conduct tests of the adaptability of some identified pheromones for insect pests available in Bangladesh.
6. It is also important to expand IPM practice to many economically importance crops like fruits, pulses, rice, vegetables etc.
7. The farmers should also be motivated to minimize their dependence on the only use of chemical pesticides to control the harmful insect pests.
8. It is also important to conduct appropriate and useful training programs on the use of pheromone technologies with farmers and field-level agricultural officers and researchers.
9. The attempts on pheromone technologies should be transferred directly to the field.

Conclusions

Pheromones are semiochemicals produced by various insects for their communications. Although pheromones are not insecticides in nature, their conjugated usages with adhesive material and insecticide have proven useful in managing the insect pests in agriculture. Various categories of synthetic pheromones that are produced in laboratories and factories play a key role in biorational management of several crop pests. These pheromones lure insects and subsequently trap them. The eco-friendly properties and lower cost, make them more lucrative than the environmentally hazardous chemical insectides for the management of insect pests. Rapid progress in methodology of the detection and characterization of small quantities of pheromones produced by insects and bioassay methods for assessing their biological activity, a variety of pheromones are discovered every year from a range of insect species. However, our understanding of molecular determinants and mechanisms of pheromone perception and neural processing is still limited. For better understanding, a considerable amount of field trials and basic research are needed for their greater application in eco-friendly management of insect pests in sustainable crop production. Additionally, to make pheromone popular among the mass, more marginal farmers should be trained along with building awareness for the eco-friendly approaches for the pest management.

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