Classical Practices and Pheromones in Biopesticides

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Mohammed Iqbal Siddiqui and Mohammed S. Al-Khalifa

Abstract

Application of biopesticides is a globally rising phenomena on yearly basis, and the use of traditional insecticides is on the decline. North America uses the largest percentage of the biopesticide market share at 44 %, followed by the Europe with 20 %, each South and Latin American countries with 10 %, and about 6 % in Asia and India. However biopesticide growth is projected at 10 % annually; it is highly variable among the regions constrained by factors such as regulatory hurdles, public and political attitudes, and limitations for market expansion. Microbial biopesticides have been registered globally for 35 years, but the number of registrations for commercial restricted industry and domestic uses has significantly increased over the past 10 years.

The early Canadian biopesticides registered by pest control category were *Bacillus thuringiensis* in 1972 as the first bioinsecticide, *Agrobacterium radiobacter* in 1989 as the first biobacteriocide, *Colletotrichum gloeosporioides* sp. *malvae* in 1992 as the first bioherbicide, and *Streptomyces griseoviridis* in 1999 as the first biofungicide. Between 1972 and 2008, the Pest Management Regulatory Agency approved registration of 24 microbially active substances with 83 formulations. The majority of the registrations (55/83) occurred since 2000, and at the beginning of 2008, there were 10 new products (a combination of new active substances, strains, formulations, and uses) under regulatory evaluation. This chapter examines the evolution of microbial biopesticides illustrating how the actions of the government, the people, and the industry have led to changes in legislation, policy, and programming that spurred momentum for new microbial pest control products in recent years and created a model safe system for future microbial biopesticide discovery, development, and implementation that could be adopted throughout the world. Pheromones present new environmentally safe strategies used for insect control. Pheromones follow the process of mating disruption through chemical communication

M.I. Siddiqui (✉) • M.S. Al-Khalifa
Zoology Department, College of Science, King Saud University, P. O. Box 2455, Riyadh 11451, Saudi Arabia
e-mail: miqbals@ksu.edu.sa

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inhibitors, pheromones, and plant-based volatiles, and attractant-and-kill and push–pull strategies. Important successes have been obtained particularly in mating disruption with significant reduction in pesticide use in low to moderate pest infestations. One important factor of concern is the high cost of semiochemicals and formulations containing them in comparison to the conventional insecticide treatments, and a combined effort of researchers, producers, and farmers should be made to reduce the cost of application of these semiochemicals.

Keywords
Biopesticides • Classical practice • Pheromones • Insect control • Semiochemicals

17.1 Introduction

In principle and through strategy, the microbial control viruses, bacteria, and pheromone constitute the part of biopesticide management system. These are the key components of integrated pest management. Increased problems of resistance and contamination with conventional insecticides have assured the bright future for their substitute in the form of biopesticidal use. However the advances in the biotechnology should help bring the microbial cost decrease and its efficacy to increase, and it may be achieved through (a) fastidious production of microorganisms on artificial media, (b) single host cell can be used to accelerate the production of pathogens, (c) raising the killing, and (d) enhancing environmental stability. Ecogen Incorporation and Mycogen Corporation have used later two points and engineered two products combining more than one toxin of bacterium *Bacillus thuringiensis* when one of these products is effective in controlling gypsy moth and spruce budworm in forest and others against Colorado potato beetle and European corn borer on potatoes (Benhamou et al. 1994; Maddox 1994; Pedigo 1996; Lacey and Kaya 2000; Bailey et al. 2010). Similarly Mycogen Corporation has developed a technique to improve *B. thuringiensis* stability by engineering a rhizobacterium *Pseudomonas fluorescens* and toxin and then killing the cell. *P. fluorescens* encapsulate the toxin and make it much more resilient and useful to environmental factor. Apart from the genetic engineering of *B. thuringiensis*, similar strategy is used toward use of virus efficacy. Virus is engineered to produce juvenile hormone esterase JHE, and thus engineered virus is used to infect lepidopteran that profoundly reduces the feeding and growth of these larvae. The future of microbial control in the form of bacterial and viral insecticides or biopesticides is promising safe and would be reasonably low cost through the advancement of genetic engineering. In the past, myriad methods have been used in applying the microbial control, and all of them have culminated or are aimed at increasing mortality of the pest by increasing natural enemy to prey ratio, and another measure to raise the efficacy of biopesticide management through modifying crop production to enable the conservation of natural enemies and saving them from destruction (Sheck 1991; Kalra and Khurana 2007).

Once chemists knew that the communications among a variety of organisms are based on chemical substances termed pheromones, they isolated, identified, and synthesized hundreds of pheromones to use them practically for pest control. The same idea is at the heart of a number of initiatives to control a range of stock pests and to control a range of insects that present a risk to human health either directly or as a result of the agents of disease that they transport. The key to all of these behavioral chemicals is that they leave the body of the first organism, pass through the air (or water), and reach the second organism where they are detected by the receiver. Pheromones are a class of semiochemicals that

insects and other animals release to communicate with other individuals of the same species. Classical practices used in the application of biopesticides are grouped in three categories: introduction, augmentation, and conservation. However natural products or biochemical products are generally used as in the use of conventional insecticides. This chapter is a step forward to disseminate the information in favor of the use of biopesticide for a safe and healthy human environment. Earlier classical practice used the process of importation that include the identification of the natural enemy in their original location and then importing them to new places hence natural enemies are associated with their host with an anticipation that microbial organism would establish themselves permanently to bring the average population below the economic injury level.

Classical practices: Since distant past classical practice used the process of importation that included the identification of the natural enemy in their original location and then importing them to new places, natural enemies are associated with their host with an anticipation that microbial organisms would establish themselves permanently to bring the average population below the economic injury level.

Augmentation: It is accomplished by increasing the number of microorganisms or their effectiveness. Generally it is used temporarily for the suppression of the pest population peaks rather than effectively changing the general equilibrium position. Due to seasonal use, this practice is repeated periodically and these may be inundative or inoculative.

Inundative: Most successful releases with pathogenic microorganisms like *B. thuringiensis* mostly against lepidopteran and coleopteran larvae, mosquitoes, and blackflies showed extensive results, but there was little subsequent suppression after initial release. In case of additional outbreaks during the season, more applications of the microbes should be required.

Inoculative: These techniques have been successful against Japanese beetle in turf grass. Two bacteria cause milky disease in this insect. Beetle population is suppressed by commercial formulations of spore powder deposited on the surface and washed manually or by rainfall. In successes thus achieved, epidemic is caused in their larval population density, for example, *Bacillus thuringiensis var. san diego* for Colorado potato beetle; *B. thuringiensis var. israelensis* for mosquitoes and blackflies; *B. thuringiensis var. kurstaki* for army worm and other moths; and *B. thuringiensis var. aizawi* for wax moth.

Environmental manipulation: It is very important to reduce pest population that is obviously achieved by planting cover crops broad bean *Vicia faba* in apple orchards. Maintaining cover crop, periodically moving it, and leaving the mulch reduces the number of aphids, leafhoppers, and codling moths. In fact, this practice confuses the pest to find the host (Gould 1991; Copping 2009; Kalra and Khurana 2007).

17.2 Pheromones

Apart from the use of microbes, pheromones are also an integral part of biopesticidal strategy; it is practiced in different styles and ways. Application of the potential for using odorants in this way has targeted the control of leaf-cutting ants and the red imported fire ant (Blums and Ross 1965; Vander Meer 1996). Use of pest control or suppressing their population dates back to the early 1900s in the form of attracting baits treated with insecticides or on food and killing them outright, but the current paradigm remains largely confined to improving the performance of toxic baits (Billen and Morgan 1998; Rust et al. 2004). This kind of control is very much in practice in the control of household pests and other places where the conventional use of insecticide causes unnecessary risk through direct exposure to the dwellers. In fact, characterization of ant trail pheromones over the last several years and little use of these compounds has been implemented in pest management (El-Sayed 2012). New application technologies that deliver pheromones against invasive pest ants could help reduce our reliance on the use of insecticides for ant pest control in sensitive

ecosystem or where insecticides are undesirable. Synthetic trail pheromone was applied in combination with insecticidal bait (hereafter “bait”) in an attempt to develop a novel strategy for controlling medically important ants in a small treatment area. Trail pheromone disruption that affects recruitment is an example of a novel tactic for ant pest management. Trail pheromones are sex- and species-specific chemical compounds that affect insect behavior and bioactivity. They are active or effective in extremely low doses, one millionth of an ounce, and are used to bait traps or confuse a mating population of insects. Pheromones can play an important role in integrated pest management for household pests.

Agricultural or forest pest: Pheromones are a class of semi- or semiochemicals that insects and other animals release to communicate with other individuals of the same species. The key to all of these behavioral chemicals is that they leave the body of the first organism pass through the air (or water) and reach the second organism where they are detected by the receiver. In insects, these pheromones are detected by the antennae on the head. The signals can be effective in attracting faraway mates and in some cases can be very persistent, remaining in place and active for days. Long-lasting pheromones allow marking of territorial boundaries or food sources. Other signals are very short lived and are intended to provide an immediate message such as a short-term warning of danger or a brief period of reproductive readiness. Pheromones can be of many different chemical types to serve different functions. As such, pheromones can range from small hydrophobic molecules to water-soluble peptides (hydrophilic) suiting its diversified applications. Majority of research have been carried out on sex pheromones followed by aggregation pheromones due to their effective utilization and usefulness in pest management. To date, approximately 50 companies are involved on commercially producing synthetic pheromones (parapheromones) for more than 50 species of the dangerous pests. Among thus produced parapheromones, 80 % are for controlling Lepidoptera, 10 % for Coleoptera, and the remaining 10 % for Orthoptera, Diptera, and Hymenoptera (Ridgway et al. 1990).

Parapheromones are used in three ways: (1) in sampling and detection, (2) to attract and kill, and (3) to disrupt mating. Some of these techniques have been applied to control other animal pests including vertebrate herbivores such as deer. A major strength of pheromones is their effectiveness as part of integrated pest management (IPM) schemes because of their compatibility with biological control agents and other beneficial invertebrates such as bees and spiders. Pheromones fit neatly into the *virtuous* spiral, for example, in greenhouse IPM where the use of one biological control agent such as a predatory spider mite encourages (or requires) moving away from conventional pesticides for other pests (van Lenteren and Woets 1988).

Affluent attractants apart from the food lures are available in the form of pheromones absolutely unknown in the past. Advanced methods of their application and new formulations (products) have raised the interest in these compounds. In this chapter, we describe some important information on trail pheromone including source, optimum dose, longevity, specificity, and synthetic trail pheromone and the possibility to apply in pest control. Knowledge of insect attracting the insect of the same species was known centuries ago. This pheromone (trans, *cis*-10, 12-hexadecadien-1-ol) was isolated from silk worm, and it was a sex attractant resulting in the successful mating in the same species. To date, hundreds of pheromones have been isolated so far ranging from algae to primates due to the research advancement in analytical chemistry.

Sex pheromones: Generally sex pheromones are secreted by females to attract their counterpart males, but these may also be secreted by some males. Although removal of adult males unless at a very high proportion of the population is unlikely to have a large impact on the size of subsequent generations compared to removal of females (Lanier 1990). Pheromones for many insect pests have been identified. For example, a website “Pherolist” cites more than 670 genera from nearly 50 families of Lepidoptera in which female sex pheromones have been identified (Tumilsom et al. 1977; Arn et al. 1995; Fónagy et al. 2011). These are secreted by eversible

gland at the tip of the abdomen of the lepidopteran insects through a very complex process depending on the maturity of the insects, photoperiod, and light. This is perceived by the males through the sensillae on the antennae of the males. This is used in diverting the males away from the females and thus suppressing their numbers as a control method. These pheromones are commonly used as attractants to facilitate contact with and dispersal of pathogens in pest populations (Pell et al. 1993).

Trail-marking pheromones: Pheromones are the specialty of foraging ants and mites and used to communicate the food requisites to the other members of the community, and it can be used to deceive and deprive them from the food and suppress their population. Chemical trail communication allows group foragers to exploit conspicuous food sources efficiently and represents the most prevalent form of recruitment behavior (Mashaly 2010, 2011; Mashaly et al. 2008; Sillam et al. 2007). Trail communication is more commonly based on a multicomponent system where the secretions of different glands (or a blend of pheromones produced by the same gland) may contribute to the structure of the trail and regulate different behaviors in the process of recruitment (Hölldobler and Wilson 1990; Jackson et al. 2006; Mashaly et al. 2008, 2010, 2011; Mashaly and Al-Khalifa 2012).

These pheromones are utilized by animals as navigational aids in passing directional hints to other members of the colony to a distant location, varying in length from hundreds of meters in bees to few meters in terrestrial insects. The reasons for orienting members of the colony to a distant point may vary. In most cases, trails are laid by foraging workers as they return from a food source. These trails are then used by other foragers (Wilson and Pavan 1959). In other cases, however, trails may be laid to recruit workers for slave raids, colony emigration, or the repair of a breach in the nest wall (Wilson and Pavan 1959). Different types of trail marking are found in terrestrial insects and flying insects. The terrestrial insects appear to lay a continuous or nearly continuous trail between points. Wilson (1962) had shown that the fire ant *(Solenopsis saevissima)* drags its sting and lays a trail in a manner similar to a pen inking a line. If the food source is of good quality, other workers choose to reinforce this trail and a highway several centimeters wide may be formed.

Aggregation pheromones: Some of the coleopterans are known to attract their community members on food sites, reproductive habitats, and also hibernation sites, an example of which is bark beetle. Aggregation pheromones lead to the formation of animal groups near the pheromone source either by attracting animals from a distance or stopping ("arresting") passing conspecifics (Wyatt 2003). In contrast to sex pheromones (which attract only the opposite sex), aggregation pheromones by definition attract both sexes (and/or possibly larvae). Nymphs of the German cockroach *Blattella germanica* (Sakuma and Fukami 1990). Their ability to attract females makes these pheromones well suited for the attract-annihilate method (Lanier 1990). Aggregation pheromones have been used successfully for controlling various Coleoptera including the cotton boll weevil *Anthonomus grandis* in the USA (Hardee 1982) and bark beetles in North America and Europe (Lanier 1990). Innocenzi et al. (2001) characterized a male-produced aggregation pheromone of *Anthonomus rubi* as a 1:4:1 blend of grandlure I, grandlure II, and lavandulol (note that "grandlure" is the name given to four components in the aggregation pheromone lure of the cotton boll weevil *Anthonomus grandis* Boh).

Alarm pheromones: This pheromone is peculiar in the ants and bees, and the remaining sting apparatus of a honeybee in the victim's body releases this pheromone to attract other members of the same community for attack in defense. These are used in killing the pest through entangling them on sticky substance or kill them by use of microbes or chemicals. It is achieved by trapping the pests by slow release of pheromones and insecticides in the form of small particles. The pest control is also attempted by mating disruption through air permeation with synthetic pheromone; thus, mating is disrupted because they are unable to reach their counterpart or opposite sex. Mode of action of this type of pheromone is to induce alert in conspecifics to

raise a defense response and/or to initiate avoidance (Rechcigl and Rechcigl 1998). Weston et al. (1997) showed a dose response of attraction and repellency for several pure volatiles from the venom of the common and German wasps *Vespula vulgaris* and *V. germanica*. The compounds are usually highly volatile (low molecular weight) compounds such as hexanal, 1-hexanol, sesquiterpenes (e.g., (E)-β-farnesene for aphids), spiroacetals, or ketones (Francke et al. 1979). Alarm pheromones of aphids have been used commercially to increase the effectiveness of conventional pesticides or biological control agents such as the fungal pathogen *Verticillium lecanii* (Howse et al. 1998). The synthetic alarm pheromones and the increased activity of the aphids in response to their alarm pheromone increase mortality because they contact more insecticide or fungal spores (Pickett et al. 1992).

The trail pheromone is secreted by the poison gland, and Cross et al. (1982; Sillam-Dussès et al. 2007) have reported it in the genus *Atta* such as *A. sexdens arbropilosa* Forel; in *Monomorium* such as *M. niloticum*, *M. najrane*, *M. lepineyi*, and *M. bicolor*; and in *Tetramorium* such as T. *simillimum*. Pygidial gland is the synonym of anal gland and it can be found in all other subfamilies except the Formicinae. In Dolichoderinae, the pygidial gland is usually very large and serves the purpose in defense and alarm (Morgan 2008). Termite predation by the ponerine ant *Pachycondyla laevigata* is responded by a recruitment trail pheromone originating from the pygidial gland that was previously reported from the hindgut. Pygidial gland opens between the 6th and 7th abdominal terga and is covered with a special cuticular structure serving as a glandular applicator (Hölldobler and Traniello 1980).

17.3 Chemical Composition of Pheromones

Pheromones are chemically classified into different categories to serve different functions, and this range includes small hydrophobic molecules to water-soluble peptides (Sunamura et al. 2011). The main ways of utilizing an understanding of pheromones to control pests are monitoring mating disruption, "lure and kill" or mass trapping, and other manipulations of pest behavior (Billen and Morgan 1998; Blum and Ross 1965; Fónagy et al. 2011). Some of these techniques have been applied to control other animal pests including vertebrate herbivores such as deer. A major strength of pheromones is their effectiveness as part of integrated pest management (IPM) schemes because of their compatibility with biological control agents and other beneficial invertebrates such as bees and spiders. Pheromones fit neatly into the *virtuous* spiral, for example, in greenhouse IPM where the use of one biological control agent such as a predatory spider mite encourages (or requires) moving away from conventional pesticides for other pests (van Lenteren and Woets 1988; Tangchitphinitkan et al. 2007).

Pheromones are a class of semiochemicals that insects and other animals release to communicate with other individuals of the same species. The key to all of these behavioral chemicals is that they leave the body of the first organism, pass through the air (or water), and reach the second organism where they are detected by the receiver (Free 1987). In insects, these pheromones are detected by the antennae on the head. The signals can be effective in attracting faraway mates and in some cases can be very persistent, remaining in place and active for days. Long-lasting pheromones allow marking of territorial boundaries or food sources. Other signals are very short lived and are intended to provide an immediate message such as a short-term warning of danger or a brief period of reproductive readiness. Some of the chemicals secreted by respective insect of economically important pest are listed with their finder's references in the Table 17.1.

Epideictic pheromones: These are also known as spacing pheromones, and their main endeavor is to repel from the crowded food source and reduce their numbers. These are used to reduce competition between individuals and are known from a number of insect orders (Hummel and Miller 1984). These are mainly produced by the bark beetles and other insects belonging to Lepidoptera, Homoptera, Hymenoptera, and Orthoptera. Its best example is the apple maggot *Rhagoletis pomonella* (Tephritidae). Females ovipositing in

Table 17.1 Chemical nature of the pheromones

S. no.	Pheromone	Name of the insect species	Chemical formula	Reference
Alcohols				
1	Seudenol	*Dendroctonus pseudotsugae*	$C_7H_{12}O$	McKnight (1978)
2	Sulcatol	*Gnathotrichus sulcatus*	$C_8H_{16}O$	Borden et al. (1976)
3	Grandisol	*Anthonomus grandis*	$C_{10}H_{18}O$	Mori et al. (1978)
Acetates and propionate				
1	Acetate of (Z)-6-isopropenyl-3-methyl-3 9-decadien-1-1	*Aonidiella aurantii*	$C_{16}H_{26}O_2$	Roelofs et al. (1978)
2	Acetate of (E)-6-isopropyl-3 9-dimethyl-58-decadien-1-1	*Aonidiella citrina*	$C_{17}H_{30}O_2$	Roelofs et al. (1982)
3	Propionate of (Z)-6-isopropenyl-3 9-dimethyl-3 9-decadien-1-$_0$1	*Pseudaulacaspis pentagona*	$C_{18}H_{30}O_2$	Heath et al. (1980)
Aldehydes and ketones				
1	Franal	*Monomorium pharaonis*	$C_{17}H_{30}O$	Kobayashi et al. (1980)
2	Trogodermal	*Trogoderma granarium*	$C_{17}H_{32}O$	Levinson and Mori (1980)
3	311-Dimethyl-2-nonacosanone	*Blattella germanica*	$C_{31}H_{62}O$	Mori (1981)
Acids esters and lactones				
1	4-Hexanolide	*Trogoderma glabrum*	$C_6H_{10}O_2$	Ravid et al. (1978)
2	Callosobruchusic acid	*Callosobruchus chinensis*	$C_{10}H_{16}O_4$	Mori et al. (1983)
3	Dominicalure 1	*Rhyzopertha dominica*	$C_{11}H_{20}O_2$	Williams et al. (1981)
Acetals and epoxides				
1	Dominicalure 2	*Rhyzopertha dominica*	$C_{12}H_{22}O_2$	Williams et al. (1981)
2	(Z)-5-Tetradecen-4-olide	*Popillia japonica*	$C_{14}H_{24}O_2$	Tumlinson et al. (1977)
3	Frontalin	*Dendroctonus frontalis*	$C_8H_{14}O_2$	Wood et al. (1976)
4	exo-Brevicomin	*Dendroctonus brevicomis*	$C_9H_{16}O_2$	Wood et al. (1976)
5	Lineatin	*Trypodendron lineatum*	$C_{10}H_{16}O_2$	Slessor et al. (1980)
6	α-Multistriatin	*Scolytus multistriatus*	$C_{10}H_{18}O_2$	Elliott et al. (1979)
7	Disparlure	*Porthetria dispar*	$C_{19}H_{38}O$	Iwaki et al. (1974), Vitae et al. (1976)

fruit mark the surface to deter other females. This behavior has also been studied in the related cherry fruit fly (*Rhagoletis cerasi*). Egg laying is a key stage determining subsequent population density so it is perhaps not surprising that there is considerable evidence of such pheromones affecting gravid females of herbivores. There is also exploitation of prey host marking and sex pheromones by parasitoids which use the signal persistence of these intraspecific cues to find their hosts. Mating-deterrent pheromones are also known from a number of insects, including tsetse flies, houseflies, and other Diptera. These pheromones are released by unreceptive females to deter males from continuing mating attempts (Rechcigl and Rechcigl 1998; Taymour 2012).

Source of trail pheromones: Generally the source of trail pheromones are hind tibia,

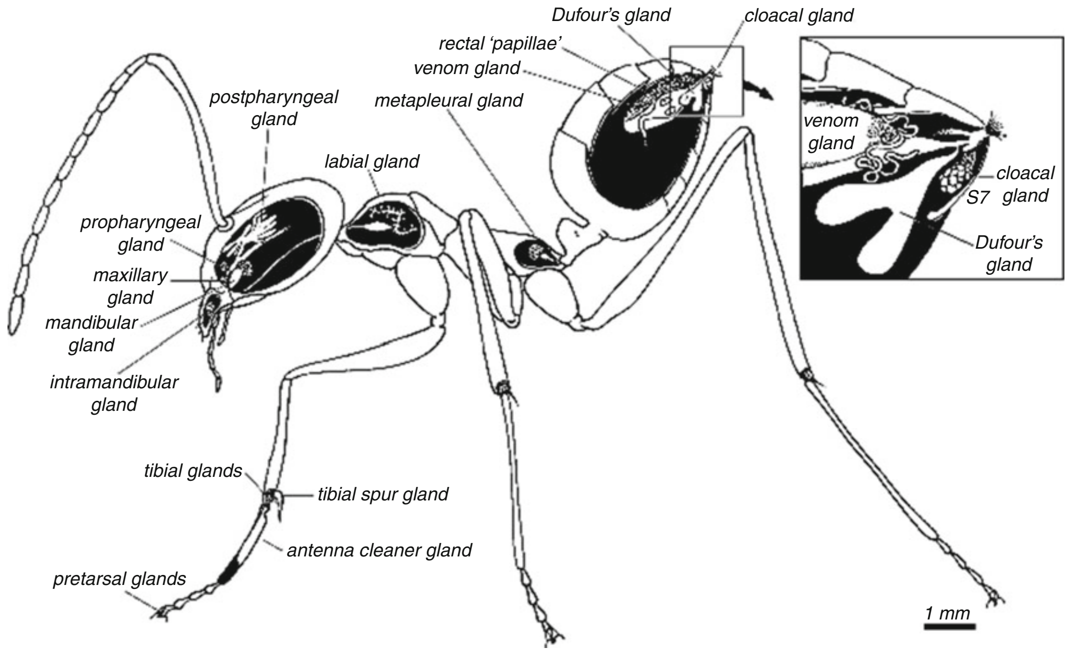

Fig. 17.1 Diagrammatic sketch of the worker ant showing the distribution of different exocrine glands. *Inset* is the enlarged abdominal tip showing cloacal gland, Dufour's gland and venom gland (Wenseleers et al. 1998)

Dufour's gland, and venom glands in Myrmicinae; Pavan's gland in Dolichoderinae; pygidial gland in Ponerinae; post pygidial gland in Aenictinae; and the hind gut in Fig. 17.1. Dufour's gland of at least a portion in Myrmicinae, Dolichoderinae, Ponerinae, and Formicinae secretes and contains mixture of straight chain of hydrocarbons ranging between C9 and C27 (Morgan 2008).

Commercial pheromones: Some of commercially available 209 brands of sex pheromones are produced by Pest Mall, USA, and Yingkou Tanyun Chemical Research Institute Corporation, Liaoning, China, and many other companies. Basically sex pheromone are microchemical matter secreted outside their bodies by female insects to be used for luring male insect mating; it is also called the sex information hormone or sex luring agent; it is mainly used in pest for casting, preventing, and curing (the luring and extinguishing method or disturbing mating method, namely, the loosing bearing method); insect sex pheromone is a new drug for eliminating pest which is efficient nonpoisonous harmless to beneficial insect not polluted to environment, and its activity is highly beneficial and remarkable; this technical achievement had been awarded the first-class prize of research achievements on science and technology in Yingkou City, China in 1980. Some of these brands are listed in Table 17.2.

17.4 Role of Biopesticides in Integrated Pest Control

In health-conscious society, the use of biopesticide in the coming 5 years would reach 10 %. Though in the year 2000 the use of biopesticides was just 0.2 %, in 2005 it reached 2.5 % and in 2010 it climbed to 4.5 % (Burges 1998; Thakore 2006; Taymour 2012). The 40 % of the biopesticides are used in the USA and 20 % in European countries. The prospects of biopesticides are excellent due to its low-cost research, easy availability, and health-friendly environment. Today communities are more health conscious than ever (Gould 1991; Sheck 1991; Rechcigl and Rechcigl 2000;

Table 17.2 Commercially available brands of pheromones

S. No.	Pheromone	Brand name	Category	Manufacturer
1	Indian meal moth pheromone	4 allure pack	Biopesticides/biological pesticides	Pest Mall, USA
1	*Carposina sasakii* sex pheromone	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
2	Hot sale insect sex pheromone	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
3	Tomato leaf miner	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
4	Pink bollworm	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
5	*Feromona spodoptera*	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
6	*Pectinophora* insect sex pheromone	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
7	*Leptinotarsa decemlineata*	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
8	Manufacturer of sex pheromone traps	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)
9	High-quality insect sex pheromone	Tanyun	Agrochemicals and pesticides	Liaoning, China (Mainland)
10	Supply sex pheromone of *Grapholita molesta*	Tanyun	Biopesticides/biological pesticides	Liaoning, China (Mainland)

Tangchitphinitkan et al. 2007; Sinha and Biswas 2008; EPA 2013).

Merits: Merits of using biopesticides are nontarget species, are substantially safe, and show least impact; harmful residues are nonoccurring; locally produced biopesticides are low cost and cost saver, and comparatively more use of these have more impact in the long-term strategy (suggested by the LUBILOSA Programme). One of the demerits of the pheromones is that the cost is high.

17.5 Conclusion

The concept of biopesticides to modify insect development and behavior exerts unique approach for the management of insect population. These products and methods of their application are based on the principle to provide safety to the environment and human. Extensive research is on the way and more is required to achieve improvement in the future. The future of the biopesticides would entirely depend on the adoption of their application. Versatile use of these must meet the standard of the established management procedures and means that they must be able to manage and suppress the harmful insect pest and prevent them from their colonization, relatively in a compatible manner to that of conventional methods. Researchers, farmers, and producers should extensively explore their utility and findings for the safe environment and more production of their crops.

17.6 Future Recommendations

1. Multiple or mixed cropping should be encouraged or followed in the practice of biopesticides in the field.
2. Provide means to develop better understanding about managing pest by the end users through seminars conferences and publications.
3. Researchers, producers, and farmers need to evolve strategy to ensure regular availability of biopesticides in the market or to stabilize their market, ensuring their prevalence to us.

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