□ 보 문 □

韓應昆誌 31(3):276~288(1992)
Korean J. Appl. Entomol.

Chemical Ecology in Insect Pest Mangement

Zhi He Guan

Department of Plant Protection, Beijing Agriculture University, Beijing 100094, P.R. China

ABSTRACT In this paper, the author gave a brief review on the meaning and background involving the growth of chemical ecology. Semichemicals which might be developed as insect control techniques incorporating in IPM program were described. The relevant semichemicals were grouped under separate topics including intraspecific semiochemicals, or pheromones (sex pheromones, alarm pheromones, and epidiectic pheromones), and interspecific semiochemicals, or allelochemics (allomones of plant origin, and kairomones favoring natural enemies). Here, the author dealt with those of practical aspects only. The prospects of chemical ecology in insect pest management were also proposed.

KEY WORDS Chemical ecology, semiochemicals, pheromones, allomones, pest management

INTRODUCTION

Chemical ecology, as defined by Michel Barbier (1976), is the science of the chemical relationships between living organisms, or between the living and the mineral world. These interactions are characteristics of life itself. Primarily, it is not a fresh idea. Since early in 1792, Lavoisier had a clear idea of the role of the circulation of the elements in the living world(from Barbier 1976). That is the fundamental concept for the natural rule. But only when environmental pollution has become increasingly serious that threatened the lives of human beings, man has been forced to reconsider the nature rule: we cannot keep ignoring our environment. It becomes one of the keys which helps us attain such knowledge searching for a better understanding of nature.

A further concept of chemical ecology was founded by Florkin (1966) who stated; "It was clearly appears that in the network of the biochemical continuum, a flow of specific molecules or of micromolecules which carry a certain quantity of information is taking place." Living organisms of both kingdoms, plants and animals, interact with the immediate environment by means of chemical molecules, animals affect animals or plants, plants affect plants or animals. So the study of these interactions and the study of the chemicals responsible for these interactions is the domain of chemical ecology (Sondheimer & Simeone 1970). Of course, it can be put into execution only when the improvement of modern analytical communications, involve a large number of very small amounts of substances, which were termed as "semiochemicals" by Law and Regnier(1971).

Here is a table of classification of various types of interactions supposed by Whittaker and Feeny

Table 1. Classification of the various types of interactions according to Whittaker and Feeny(1971)

Ⅰ. *Interspecific chemical effects (or allelochemical effects)*
A. *Allomones*: adaptive advantages for the producing organism.
1. Repellents.
2. Escape substances (inks of cephalopods, etc.).
3. Supressents (antibiotics, etc.).
4. Venomes.
5. Inductants (which cause galls and nodules).
6. Counteractions.
7. Attractants (attraction of the prey towards the predator).
B. *Kairomones*: adaptative advantages for the receiving organism.
1. Chemical lures.
2. Inductants which stimulate adaptation (for example the factor responsible for spine-development in rotifers).
3. Signals which warn the receiving organism about danger or toxicity.
4. Stimulants (growth factors).
C. *Depressants*: wast products, etc., which inhibit or poison the receiving organism without resulting in any adaptive advantage for the producer.
Ⅱ. *Intraspecific effects*
A. *Autotoxins*: waste products toxic for the producer without any advantage for other species.
B. *Adaptation auto-inhibitors*: limiting population levels to their equilibrium position in the environment.
C. *Pheromenes* :
1. Sex pheromones 2. Social pheromones 3. Alarm and defence pheromones
4. Territory-and trail-marking pheromones, etc.

(1971) (Table 1). On the table, most of the interactions are related to insect behaviors.

I wouldn't like to discuss theoretically on chemical ecology and the principles in broad sense might be useful for managing the pests(insects, pathogens, seeds, etc.) as a whole. The works by Barbier (1976), Rice(1983), Bell and Carde(1984), Harborne(1988), and Spencer(1988) provided very good compilations on such topics. I am trying to give a brief sketch only on semiochemicals, both intra- and interspecific, involving in insect pest management, though many of them are not yet used in practice.

INTRASPECIFIC SEMIOCHEMICALS : THE PHEROMONES

In 1959, Karlson and Lascher supposed the term "pheromones", and defined as "substances which are secreted to the outside by an individual and received by a second individual of the same species in which they release a specific reaction, for example, a definite behavior or developmental process". The problems of pheromones have interested many reseachers, biologists(especially entomologists) and chemists, because theoretically they are important in elucidating the specific behavior, species differentiation, caste determination and phylogenetic relationships, and practically, they would be hopeful to develop new pest-managing agents which are safe to non-target organisms, without pollution and hardly to be resistant in target pests.

Recently, Jutsum and Gordon(1989) grouped the pheromones into several types: sex pheromones, aggregation pheromones, alarm pheromones, epideictic pheromones, trail pheromones, ovarian inhibitors and phase transformers, of which three or four types are in being developed to be pest-managing agents.

Sex pheromones

Sex pheromones may be produced by females or by males according to species contributing to the communication involving in mating. They are probably the most widely studied group of insect pheromones, and have been recognized and characterized in different species. In the case of Lepidoptera, pheromones have been identified in over 500 species and new ones are being reported almost daily (Harbone 1988). For a long time, the scientists of insect behavior, as well as chemists, have proved that sex pheromones are so active in the biological system that the male begins to react when the molecular concentration is as low as 100 molecules/ml of air. A single female moth releasing its pheromone downwind from a particular site will produce an "active air space" several kilometers long and over a hundred meters in diameter (Wilson 1972).

Table 2. Structures of some typical aliphatic insect pheromones(Harborne, 1988)

Structure and name[a]	Sex	Organism
$CH_3(CH_2)_3CO_2H$	♀	Sugar-beet wireworm
Valeric acid		*(Limonius californicus)*
$CH_3CO(CH_2)_5CH=CHCO_2H$	♀	Honeybee*(Apis mellifera)*
(E)-9-keto-2-decenoic acid		
$CH_3(CH_2)_2CH=CH(CH_2)_7OAc$	♀	Oriental fruitfly
(Z)-8-dodecenyl acetate		*(Grapholitha molesta)*
$CH_3CH_2CH=CH(CH_2)_{10}OAc$	♀	Oak leaf rollermoth
(Z)-11-tetradecenyl acetate		*(Archips semiferanus)*
(E)-11-tetradecenyl acetate		
$CH_3(CH_2)_{15}OA_c$		
Hexadecanyl acetate		Butterfly
$CH_3(CH_2)_4CH=CH(CH_2)_{10}OAc$	♂	*(Lycorea ceres ceres)*
(Z)-11-octadecenyl acetate		
$CH_3(CH_2)_9CO(CH_2)_3CH=CH(CH_2)_4CH_3$	♀	Douglas fir tussockmoth
(Z)-6-heneicosen-11-one		*(Orygia pseudotsugata)*

[a] In the older literature, *cis*-and *trans*-are used instead of (Z) and (E) to indicate differences in stereochemistry around the double bond.

Chemicals to be active in such a system must be highly volatile and of a relatively low molecular weight. The simplest one is valeric acid, the female pheromone from the sugar-beet wireworm. The majority, however, are long chain unsaturated alcohol, acetates or carboxylic acid (Table 2). It is worth nothing that almost no sex pheromone contains only one component. They are mixture of major and minor components in strictly defined ratios, as well as the geometrical and optical isomerism of the molecules (Lofstedt & Odham 1984). In studying the sex pheromones of geometrid and noctuid moths, Millar et al. (1991) found that chiral and achiral attractant for one species often acted as antigonists for closely related or sympatric species, indicating now discrete chemical communication channels may maintained.

Since successful mating and high reproductivity are requisite factors for building up high density population, applied entomologists have been attracted to develop sex pheromone techniques, mass trapping and confusion, for controlling the pest population under economic injury level.

More than 15 years' field trials showed that only very few are successful in providing adequate control of the pest species by mass trapping only. Successful examples were: the Egyptian cotton leaf worm, *Spodoptera littoralis*, in Iseal where the mass trapped area was 20,000 ha. in 1981. With a trap density of 1 trap per 0.5-0.6 ha., the results are promising (Shani 1982). But the same method is not suitable in Egypt and Crete (Campion & Nesbitt 1981). The citrus flower moth, *Prays citri*, was also successfully supressed in Isreal where sticky traps and funnel traps with renewable sticky floor were used by 120-140 traps per hectare. Today almost all lemon growers in Isreal use phromone for male mass trapping to control that pest, and insecticides are generally not used against it (Shani 1982). Mass trapping of *Ips typographus*, in Norway and Sweden, constituted a major part of the integrated control programme, but was combined with other measures. The major long-term objective was to stimulate increased harvesting of overmatured stands in areas threatened by the beetles (Bakke & Lie 1989). The sitution was quite similar in China where mass trapping was only successful in controlling peach moth, *Grapholitha molesta*, in North China.

Confusion is the measure of permeating the atmosphere around calling insects with higher concentration of their own sex pheromone than they normally produce, so to prevent one sex using the natural pheromone plume to locate the opposite sex. Alternatively, the high concentration of pheromone may lead to the habituation of the nervous system, preventing any response to the pheromone. Theoretically, it would be easier to be successful than using traps, if the pheromone formulation and slow-releasing agents, microcapsules, hollow fibers, laminate flakes or polyetylene tubes, etc. are adequately selected for a given pest. Pink bollworm, *Pectinophora gossypiella*, was an example of successfully suppressed pest by confusion techniques in many countries, France, the United States, Egypt, Pakistan and Peru(Campion et al. 1989). It was also successful in East China. One of the favorable factors for this pheromone (gossyplure) is that it contains only two components and is relatively stable, which makes it particularly suitable as a selective control agent with a potentially large worldwide market. Furthermore, in many localities, this pest is the only key pest, of which the infestation is over economic threshold. Practically, any crop damaged by a complex population of insect pests might be protected by integration of pheromones and conventional pesticides. It is also right in using mass trapping.

Even though the sex pheromones technique have not been applied as conventional measures in pest management, almost all the pheromones as trapping bait were proved to be valuable in monitoring and spray timing. Again, I would like to say that the ecological benefit(protecting the natural enemies, see Table 3) and the side benefit (honey production) shouldn't be overlooked as compared with applying pesticides. But more biological studies of the target species, such as mating behavior, duration of adulthood, overlapping of generations, etc. are necessary.

Alarm pheromones

Alarm pheromones which stimulate escape and other defensive behavior have been observed in members of Dictyoptera, Hemiptera-Homoptera and eusocial Hymenoptera. But only the alarm pheromone released by aphid has been considered to be developed as an aphid repellent.

Table 3. Mean numbers of predatory insects per hectare in cotton sampled by D-Vac suction apparatus following the first application of insecticide in pheromone- and insecticide- treated areas, Egypt, 1983 (Campion et al. 1989)

Genus		Insecticide treated		Pheromone treated	Ratio (insecticides : pheromone)	
		Area 1	Area 2	Area 3	1 : 3	2 : 3
Coccinellida	adults	33	250	3717	1 : 112.6	1 : 14.9
Paederus	adults	417	17	1717	1 : 4.1	1 : 101
Scymnus	adults	33	0	1184	1 : 35.9	–
Chrysoveria	adults	17	0	200	1 : 11.8	–
Orius	adults	0	0	583	–	–
Orius	nymphs	0	0	183	–	–
Total		500	267	7584	1 : 15.2	1 : 28.4

When aphids are attacked or over crowed, they release a non-specific alarm pheromone, (E)-beta-farnesene, formerly known as TBF, from the cornicles (Bowers et al. 1972) to which near-by aphids respond by stopping feeding, moving away and sometimes dropping from the plant. Owing to its high volatility and non-stability, to use their pheromone as aphid repellent met with difficulty. It is still an attractive project for many entomologists and chemists because the prospect exists of using alarm pheromones to reduce not only direct aphid feeding damage but also the spread of aphid-borne plant viruses, especially of non-persistent viruses. To overcome the shortcomings, scientists have tried to improve by two ways. One was to scatter the alarm pheromone through slow-releasing techniques, microcapsules or hollow fibers; other one was to synthesize more stable mimics, of which a stable and cheaper product, (Z)-nor-farnesene, was synthesized, but the alarm activity was 1/4 of the natural pheromone (Nault & Montgomery 1977, Guan 1983). Derivatives produced by 1,4-cycloaddition reactions between acetylene-carboxylic acid esters and the aphid alarm pheromone, (E)-beta-farnesene, and analogues in which other features of the pheromone molecule were modified, were tested for activity against aphid colonization. The most active compound, formed from (E)-beta-farnesene and diundecyl acetylenecarboxylate, decreased aphid-transmitted barley yellow dwarf virus infection of autumn-sown barley (Dawson et al. 1988). Griffiths et al. (1986) reported some successful treatments with alarm pheromone/insecticide mixtures in which the pheromone increased the aphid mortality achieved by pyrethroids.

The hawthorn lace bug, *Corythucha cydoniae*, and the eggplant lace bug, *Gargaphia splani*, possess alarm pheromones that are produced in dorsal abdominal glands (DAGs). When *G. solani* nymphs are grasped, they emit secretion from both DAGs, the posterior DAG secretion alone elicits alarm, but the anterior DAG secretion may hasten the response. In *C. cydoniae*, the response is due to a synergism between the anterior and posterior DAG secretions. The alarm pheromones are interspecifically active in pattern matching the intraspecific activities (Aldrich et al. 1981).

Epidiectic pheromones

Epidiectic, dispersive or spacing pheromones elicit behavior resulting in increasing spacing between conspecifics and a reduction in intraspecific competition. Example can be found in Coleoptera, Diptera, Homoptera, Hymenoptera, Lepidoptera and Orthoptera and including oviposition-deterrent pheromones (ODP) (Jutsum & Gordon 1989).

It is naturally resonable for many scientists to consider the possibilities of using ODP as pest-controlling agents. Katsoyannos and Boller (1976) demonstrated in their trials that the faecal extracts of European cherry fruit fly, *Rhagoletis cerasi*, possess of ODP that marks fruit after egg-laying in order to avoid accidentally laying two eggs in the same fruit. The nature of the resulting pheromone has been identified by Huffer et al. (1987) as a hydroxy fatty acid conjugated with glucose and taurine. A related pheromone was found in the relative species, the apple maggot fly, *R. pomonella*, by Prokopy in 1972, and its residual activity was confirmed by Averill and Prokopy(1987). The interesting problem is how the water-soluble pheromone can maintain its effectiveness in areas with frequent precipitation in Central Europe.

The similar evidence was found in the Netherlands on *Pieris brassicae* where the water soluble oviposition-deterring pheromone rinsed from the egg batches remained its deterring activity for at least 14 days when sprayed on cabbage leaves, and for at least 7 weeks when dried on a glass surface (Schoonhoven et al. 1981). A water-and methanol-soluble oviposition-deterring pheromone was also found on eggs and in water extracts of female accessory glands of *Pieris rapae* (Schoonhoven et al. 1990). The same pheromone was found on eggs of *P. rapae* in my lab by dissolving in methanol (Huang & Guan 1987), though it is not so effective as that reported by Schoonhoven et al. in 1990.

The advantage of being easy to get the water wash and its chemical stability make it possible in practical use, though the synthesis of ODP would encounter major problem. Considerable amounts of crude pheromone could be collected by interested fruit growers by rinsing infested fruits, or as cherry growers, by rinsing trap plants, the honey-suckle bushes (*Lonicera* spp.), in water. The simple method of collecting pheromone solution from artificial oviposition devices in the laboratory would be an alternative for the production of natural pheromones. It is conceivable that to establish a deterring-trapping system might be a promising procedure available in IPM programs.

INTERSPECIFIC SEMIOCHEMICALS: THE ALLELOCHEMICS

The term "allelochemic" proposed by Whittaker (1970) and used to describe chemicals that mediate interspecific interactions, is defined as a chemical that is significant to organisms of a species different from its source for reasons other than food as such. At the present time, four types of allelochemicals are recongized; allomones, kairomones, synomones and apneumones (Nordlund 1981).

The allelochemicals play an important and complex role in biocenotic formation. Even the energy flows between different trophic levels are, to large extent, maintained by these semiochemicals. Phylogenetically, they are motive forces in coevolution. Harborne (1978, 1988),

Table 4. Secondary metabolites of plant origin known to be defensive to insects (Guan 1980)

Categories	Structures known	Examples
Amino acids	250	Canavanine
Flavonoids	1200	Procyanidin tanins
Glucosinolates	80	Sinigrin
Lignans	50	Excelsin
Terpenes*	1100	Glaucolide-A
Steroids	600	Ecdysones
Proteins	?	Lectins

* Excluding carotinoids and steroids.

and Spencer (1988) provided very excellent theoretical discussion on this topic. In practical consideration, I would like to deal with only the cases of allomones of plant origin in defending insect pests, and kairomones favoring natural enemies.

Allomones of plant origin

These are secondary metabolites, or secondary substances, of plants. The secondary metabolites, as they are called, also occur in animals, but over 80% of all known natural products (about 30, 000 structures) are of plant origin (Harborne 1977). This richness must be related at least partly to the immobility of plants: since they cannot escape environmental pressure by moving, their only defenses are their physical structures and chemical composition (Ewards & Wratten 1980). Just such chemicals constitute the basis of allomones of plant origin in defending insect pests. Up to the end of 1970s' more than 3,000 structures belonging seven catogories were recorded as defensive secondory substances of plants, of which most were found in flavonoids, terpenes and steroids (Table 4) (Guan 1980), though some of them might be possessing of biocidal properties. Gringe et al. (1985) recored 384 species of plants with antifeeding properties. Inspite of this, we cannot separate clearly between repellent and antifeeding properties according to involved references.

Hsiao (1976) reported that the selection of food plants by the larvae of the Colorado potato beetle is influenced mainly by qualitative and quantitative differences in the deterrent and repellent chemicals of the food plant. Norris' studies of hickories (*Carya*) indicated that juglone (5-hydroxy-1,4,-naphthoquinone) keeps *Scolytus multistriatus* of the bitternut hickory (*C. cordiformis*) and shagbark hickory (*C. ovata*). This compoud occurs mostly as a glucoside in intact healthy cells of hockoies. Once a hockory tree becomes irreversibly diseased, it no longer can release juglone, and secondary predators and parasites that attacking dying trees of several species appear on the plant. In subsequent studies, by Norris' several 1,4-naphthoquinones were tested against the elm bark beetle, and the repelling effect was found to increase with an increase in oxidation-reduction potential of the compound. Hydroxyl (OH)subsitutions always made the naphthoquinone more repellent, or inhibitory, than the relative redox potential would indicate. One natural feeding deterrent was identified as mustard oil (2-phenylethyl-isothiocyanate) in the turnip roosst(*Brassica napus*) (Lichtenstein et al. 1962), and as myristin (5-allyl-methoxy-2,3-methylene -dioxybenzene) in the parsnip root (*Pastinaca sativa*) (Lichtenstein & Casida,1963). These compounds were shown to be deterrent and, indeed, insecticidal to vinegar flies (*Drosphilla* *melanogaster*), house flies (*Musca domestica*),flour beetles, mosquito larvae (*Ades aegypti*), spider mites (*Tetranychus atlanticus*), pea aphids (*Acyrthosiphon pisum*), and Maxican bean beetles (*Epilachna varivestis*). It was noted in Japan that leaves of the shrub kusagi(*Clerodendron tricotonum*) are not eaten by insects. Feeding tests with selected insects confirmed that the leaves contained feeding deterrents. and the two compounds were isolated, clerodendrin A and clerodendrin B. Relatively small amounts 200 to 300 ppm deter the feeding of insects on their usual hosts. These deterrents may prevent insect attacks on rice plants (Munakata 1970).

Dimock and Renwick (1991) sprayed cabbage plants in the field with butanol extract of *Erisimum cheiranthoides*, a wild crucifer normally rejected by ovipositing *Pieris rapae* because of the presence of deterrent cardenolides in the foliage. Extract-treated plants received significantly fewer eggs than did solvent-treated control plants. The results suggested that protection of plants by deterrents may be possible in the field over periods of time.

Tomato plants (*Lycopersicum esculentum*) cannot be the hosts of cabbageworm (*Pieris rapae*) neither by feeding nor by oviposition. The crude flavonoids extracted from tomato leaves in my lab possesses of strong antifeeding response to cabbageworms, and the alkaloids, mainly tomatine, seems hopeful to be a good oviposition-deterrent (Guan, unpublished data).

Rice (1983) presented a lot of related examples in his nice book. In principle, antifeedants do not harm members of third trophic leval. Furthermore, inhibition of feeding necessarily retards the herbivores ontogenetic development, i.e. prolongs their exposure to natural enemies. Thus, antifeedants are ideal pest-control agents to combine with entomophages (Jermy 1990). The problem of the effects to third trophic level seems to be worthy of being further investigated. Wang (1991), in my Division, studied gossypol, an antifeedant and growth inhibitor of cotton bollworm (*Heliothis armigera*) and its relation to an ichneumonid parasitoid, *Campoletis chloridae*. Results showed that 0.1% gossypol in artificial diet of the bollworm reduced the suitable parasitized period of the host by 10.25%: while 0.5% gossypol prolonged the suitable parasitized period by 28.15%, but caused the increment of egg-larval stage and decrement of pupal stage and adult weight and longevity.

Many studies indicated that to investigate formulations of increasing persistence for antifeedants is a prerequisite for practical application.

Kairomones favoring natural enemies.

The term "kairomone", proposed by Brown et al. (1970), was defined as a subtance produced or acquired by an organism that it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or phisiological response than is adaptively favorable to the receiver but not to the emitter (Brown et al. 1970, Nordlund & Lewis 1976). Kairomones may be chemical cues that are hormones, pheromones, allomones, and so on, to the legitimate receiver that are used by an illegitimate receiver (Otte 1974), or they may be incidental cues such as waste products.

Many beneficial insects use kairomones in their host or prey selection behavior. The larval parasitoid *Microplitis croceipes* is stimulated into intensive searching behavior by kairomones found in the frass of *Heliothis zea*, *H. virescens*, and *H. subflexa*(Lewis & Jones 1974). A substance in the mandibular secretion of *H. virescens* is used by *Cardiochiles nigriceps* in its host location behavior(Vinson 1968). *Trichogramma pretiosum* females are stimulated into an intensive search behavior by chemicals found in the scales of *H. zea* moth (Lewis et al. 1975). Vite and Williamson (1970) found that brevicomin, the bark beetle sex pheromone, was used by the predator *Thanasimus dubius* to locate its prey.

Perhaps, most detailed studies involving kairomones used by parasitoids were carried on the generalist hymenoptera egg parasitoids, the *Trichogramma* spp. with great potential for managing lepidoptera pests. Early in 1937, Laing demonstrated that *Trichogramma evanescens* received an odor left by adult moth. Apparently, this discovery has been ignored for decades until 1970s. Lewis et al. (1972) identified moth scales as the source of the mediator that stimulates the host-seeking response by the same parasitoid. Jones(1973) found that the most active chemical present in *H. zea* moth scales was a hydrocarbon, C23(tricosane), in eliciting significant orientation and stimulating parasitism by *T. evanescens*. Gross et al. (1975) proved that when tricosane and the *H. zea* moth scale extract were used as a sign stimuli for *Trichogramma achaea* and *T. pretiosum* respectively, at time of release from laboratory container, rates of parasitization on *H. zea* egg were significaltly increased, compared with rates for unstimulated parasitoids. It is to say that the innate tendancy of released wasps to disperse upon release could be overridden by exposing them, at time of release, to kairomones extracted from *H. zea* moth sacles. A special container of *Tricogramma* spp. parasitized eggs was designed with its surface or neck treated with appropriate kairomone, to expose the emerging parasitoides as they are released.

The studies on predator-prey interactions were largely based upon behavior observations. Only few chemical cues were isolated as kairomones. It is interesting that, in many cases, the predators locate the preys by using the odors other than those emitted by the preys. Green lacewing adults can be attracted by natural honeydew, as well as proteinaceous artificial honeydews, that protomote both feeding and oviposition, and ensure the availability to prey for the larvae when they emerge, so that the adult females play an important role in prey-finding by selecting a suitable environment for the larvae before oviposition. Actual prey finding is left to the larvae (Hagen et al. 1971). Further studies by Hagen et al. (1976) showed the attractive agent in artificial honeydew was the amino acid tryptophan, probably a tryptophan degradation product.

McLain(1979) found that three species of predatory penatomids follow terrestrial trail made by a variety of caterpillars. He demonstrated the artificial trail could be drawn on paper by using aqueous solutions of either frass or hemolymph from *Trichoplusia ni* larvae and found that these trails were readily followed by the predators. It seems likely that a wide array of hunting type predators, such as carassbids and cicindellids, also use kairomon trail to help locate their preys.

Spined soldier bug(*Podisus maculiventris*) orient to soybean plants infected by larvae of *Trichoplusia ni*, presulably because a chemical stimulus either from the larvae themselves or from a chemical liberated from the wounded plant tissue(Greany & Hagen. 1981). Turlings et al (1991) noted that volatiles released from corn seedlings on which beet armyworm(*Spodoptera exigua*) were feeding attractive to females of the braconid parasitoid, *Cotesia marginiventris*, in flight tunnel bioassays. When a parasitoid experiences in contacting host by-product, the respond to a particular odor blend may be dramatically increase. The evidence of learning experience of natural enemies was also found by Dicke et al (1990) in predatory mites responding spider mite-infested plants. These studies opened a new avenue leading to using indirect compounds emitted by plants in attracting natural enemies.

PROSPECTS

Numerous studies on semiochemicals have given and giving light in using non-biocidal behavioral substances as pest control agents instead of applying conventional synthetic pesticides, though, at present time, only few examples were successful in field practice. But I would like to state that it's our duty, applied entomologists' duty to reform the present situation, as we know, we are facing the serious problem of environmental crisis, even though we have to overcome many difficulties on the way we are marching.

As described above, chemical ecology is a science that prove keys which help us attain the knowledge searching for a better understanding of nature. But in reality, we have got only very few "keys" to understand the nature. That's why we can not manipulating the rule in developing semiochemicals as tools of pest management.

1. The communicating chemicals are mostly blend compounds of which each component may display as major, minor, or synergist. Their optimum ratio and stereoisomerisms should be clarified as well. It is a key enhancing the bioactivities for application purposes.
2. The biology and behavior of target pests are remained to be studied more thoroughly. Even some simple biological knowledge, the lifespan of adulthood, or overlapping of generations, might be available in evaluating the possibilities of suppressing the target population by semiochemicals. The habitat and ecological niche in which many organisms living togather in complex mutual relationships may play important roles in using semiochemicals.
3. More attention should be paid on the toxicity, stability, and degradation of secondary metabolities used as allelochemics. Mimics and derivatives may be synthesized, but many evidences showed that almost all the related compounds may induce resistance in insects.
4. Economic considerations are also the problem influencing semiochemicals in practical use. But people with foresight and sagacity shouldn't ignore the benifits retrieved from protecting natural enemies, preserving wild resources and biological diversity, improving the environmental quality, and protecting human from the injury of pollution, which are impossible counted according to pure economic point of view.

In concluding my speech, I would like to cite a sentence presented on the letter from Dr. William K. Reilly, the Administer of United States Environmental Protection Agency, to famous chemical ecologists, Drs. Thomas Eisner and Jerrold Meinwald for congratulating them being elected as Tyler Prize Laureates of 1990. "If there is a 'secrete of life', it is surely communication".

REFERENCES

Averill, A.L. & R.J. Prokopy 1987. Residual activity of oviposition-deterring pheromone in *Rhagoletis pomonella* (Diptera: Tephitidae) and female response to infested fruit. J. Chem. Ecol. 13, 167~177.

Bakke, A. & R. Lie 1989. Mass trapping. In Jutsum, A.R., and R.F.S. Gordon (eds.) Insect Pheromones in Plant Protection. John Wiley & Sons, N.Y.

Barbier, M. 1976. (English translation by M. Ferenczi, 1979) Introduction to Chemical Ecology. Longman, London.

Bell, W.J. & R.T. Carde 1984. Chemical Ecology of Insects. Sunderland, Massachusetts.

Bower, W.S., L.R. Nault, R.E. Webb & S.R. Dutky 1972. Aphid alarm pheromone: isolation, identification, synthesis. Science 177, 1121~1122.

Brown, W.L., Jr., T. Eisner & R.H. Whittaker. 1970. Allomones and kairomones: transspecific chemical messenger. BioScience 20, 21~22.

Campion, D.G., B.R. Critchley & L.J. McVeigh 1989. Mating disruption. In Justum, A.R., & R.F. S. Gordon (eds.) Insect Pheromones in Plant Protection. John Wiley & Sons, N.Y.

Campion, D.G. & F. Nesbitt. 1981. Recent advances in the use of pheromones in developing countries with particular reference to mass-trapping for the control of the Egyptian cotton leafworms *Spodoptera littoralis* and mass disruption for the control of pink bollworm *Pectinophora gossypiella*. In Les Médiateurs Chimiques Agissant sur le Comportment des Insectes, Institut Nationel de la Recherche Agronomique, Paris, pp.335~342.

Dowson, G.W., D.C. Griffiths, J.A. Pickett, R.T. Plumb, C.M. Woodcock & Zhang Zhong-ning 1988. Structure/activity studies on aphid alarm pheromone derivatives and their field use against transmission of barley yellow dwarf virus. Pest. Sci. 22, 17~30.

Dicke, M., M.W. Sabelis, J. Takabayashi, J. Bruin & M.A. Posthumus. 1990. Plant strategies of manipulating predator-prey interactions through allelochemicals: prospects for application in pest control. J. Chem. Ecol. 16, 3091~3118.

Dimock, M.B. & J.A. Renwick 1991. Oviposition by field population of *Pieris rapae* (Lepidoptera: Pieridae) deterred by an extract of a wild crucifer. Environ. Entomol. 20,802~806.

Edwards, P.J. & S.D. Wratten 1980. Ecology of Insect-Plant Interactions. Edward Arnold, London.

Florkin, M. 1966. Aspects Moléculaire de l' Adaptation et de la Phylogénie. Masson, Paris.

Grainge, M., S. Ahmed, W.C. Mitchell & J.W. Hylin 1985. Plant Species Reportedly Possessing Pest-Control Properties--A EWC/UH Database. Unversity of Hawaii.

Greany, P.D. & K.S. Hagen. 1981. Prey selection. In Nordlund, D.A., R.L. Jones, & W.J. Lewis (eds.) Semiochemicals: Their Role in Pest Control. John Wiley & Sons, N.Y.

Griffiths, D.C., G.W. Dawson, J.A. Pickett, C. Woodcock 1986. Use of the aphid alarm pheromone and derivatives. Proc. Brit. Crop Prot. Conf.

Guan, Z.H. 1980. The relationships between the defensive secondary substances of plants and insects. Nature Journal 3, 848~851 (in Chinese).

Guan, Z.H. 1983. Aphids and Plant Virus Diseases. Kuizhou Peoples' Publishing Co., Kuiyang (in Chinese).

Hagen, K.S., P.D. Greany, E.F. Sawall, Jr. & L. Tassan. 1976. Tryptophan in artificial honeydews as a source of an attractant in adult *Chrysopa carnea*. Environ. Entomol. 2, 456~458.

Hagen, K.S., E.F. Sawall, Jr. & L. Tassan. 1971. The use of food sprays to increase effectiveness of entomophagous insects. Proc. Tall Timbers Conf. Ecological Animal Control by Habitat Management 2, 59~81.

Harborne, J.B. 1977. Introduction to Ecological Biochemistry. Academic Press, London.

Harborne, J.B. 1978. Biochemical aspects of Plant and Animal Coevolution. Acadamic Press, London.

Harborne, J.B. 1988. Introduction to Ecological Biochemistry (3rd ed.). Academic Press, London.

Hsiao, T.H. 1976. Chemical and behavioral factors influencing food selection of Leptinotarsa beetle. In Jermy, T.(ed.) The Host-plant in Relation to Insect Behavior and Reproduction. Plenum Press, N.Y.

Huang, X.P., 1991. Advances in chemical ecology of insects-A critical review. Acta Agriculturee Universitis Pekinensis 17(4), 103~112 (in Chinese).

Huang, X.P. & C.H. Kuan 1987. Electroantennogram and oviposition-deterring responses of Antrogeia rapae to some semiochemicals of plant origin and conspecific eggs. ibid, 13, 299~3 09 (in Chinese, with English Summary).

Hurter, J., E.F. Boller, E. Staedler, B. Blattmann, H.R. Buser & N.U. Bosshard. 1987. Oviposition -deterring pheromone in *Rhagoletis cerasi* L.: purification and determination of the chemical constitution Experimentia 43, 157~164.

Jermy, T. 1990. Prospects of antifeedant approach to pest control--A critical review. J. chem. Ecol. 16, 3151~3166.

Jutsum, A.R. & R.F.S. Gordon 1989. Introduction. Pheromones: importance to insects and the role in pest management. in Jutsum, A.R. & R.F.S. Gordon (eds.) Insect Pheromones in Plant Protection. John Wiley & Sons, U.K.

Karlson, P. & M. Luscher 1959. Pheromones: a new term for a class of biologically active substances. Nature 183, 55~56.

Katsoyannos, B.T. & E.F. Boller 1976. First field application of oviposition-deterring marking pheromone of European cherry fruit fly. Environ. Entomol. 5, 151~152.

Lachtenstein, E.P. & J.E. Casida 1963. Myristicin, an insecticide and synergist occurring naturally in the edible parts of parsnips. J. Agr. Food Chem. 11, 410~415.

Lachtenstein, E.P., F.M. Strong & D.G. Morgan. 1962. Identification of 2-phenylethyl-isothiocyanate as an insecticide occurring naturally in the edible part of turnips. J. Agr. Food Chem. 10, 30~33.

Law, J.H. & F.E. Regnier. 1971. Pheromones. Ann. Rev. Biochem. 40, 533~548.

Lewis, W.J. & R.L. Jones. 1971. Substance that stimulates hostseeking by *Microplitis croceips*, a parasite of *Heliothis species*. Ann. Entomol. Soc. Am. 64, 471~473.

Lofstedt, C. & G. Odham. 1984. Analysis of moth pheromone acetates by selected in monitoring using electron impact and chemical iononization mass spectrometry. Biomed. Mass Spectrom. 11, 106~113.

Mcain, K. 1979. Terestrial trail following by three species of predatory stink bugs. Florida Entomol. 62, 154~156.

Meng, Xian-zuo, Yi-hui Wang & Meng-xian Ye. 1985. Field trial on mass trapping for the control of the oriental fruit moth with synthetic sex pheromone. Acta Entomol. Sinica 28, 142~147 (in Chinese, with english summery).

Millar, J.M., M. Giblin, D. Barton & E.W. Underhill. 1991. Chiral lepidopteran sex attractants: blends of optically active C20 and C21 diene epoxide as sex attractants for geometrid and noctuid moths (Lepidoptera). Environ. Entomol. 20, 450~457.

Manakata, K. 1970. Insect antifeedant in plants. In Wood, D.L., R.M. Silvestein, and Nakajima (eds.) Control of Insect Behavior by Natural Products. Acadamic Press, N.Y.

Nault, L.R. & M.E. Montomery. 1977. Aphid pheromones. In Harris, K.F. & M.E. Montgomery (eds.) Aphids as Virus Vectors. Academic Press. N.Y.

Nordlund, D.A. 1981. Semiochemicals: A review of the terminology. In Nordlund, D.A., R.L. Jones & W.J. Lewis (eds.) Semiochemicals: Their Roles in the Pest Control. John Wiley and Sons, N.Y.

Nordlund, D.A. & W.J. Jones. 1976. Terminology of chemical releasing stimuli in intraspecific and interspecific interactions. J. Chem. Ecol. 2, 211～220.

Otte, D. 1974. Effects and functions in the evolution of signaling systems. Ann. Rev. Ecol. Syst. 5, 385～417.

Pickett, J.A., G.W. Dawson, D.C. Griffiths, X. Liu, E.D.M. Macaulay, I.H. Williams & C.M. Woodcock 1983. Stabilizing pheromones for field use: propheromones. 10th International Congress of Plant Protection. 1, 271.

Prokopy, R.J. 1972. Evedence for a marking pheromone deterring repeated oviposition in apple maggot fly. Environ. Entomol. 1, 326～332.

Rice, E.L. 1983. Pest Control with Nature's Chemicals. University of Oklahoma Press, Norman.

Schoonhoven, L.M., E.A.M. Beerling, R. Braaksma & Y. Van Vugt 1990. Does the imported cabbageworms, *Pieris rapae*, use an oviposition-deterring pheromone? J. Chem. Ecol. 16, 1649～1655.

Schoonhoven, L.M., T. Sparnaay, W. Van Wissen & Meerman. 1981. Seven-week persistence of an oviposition-deterrent pheromone. J. Chem. Ecol. 7, 583～588.

Shani, A. 1982. Field studies and pheromone appplication in Isreal. 3rd Isreali Meeting on Pheromone Research. 1982. pp. 18～22.

Sondheimer, E., & J.B. Simeone (eds.) 1970. Chemical Ecology. Academic Press, N. Y.

Spencer, K.C. (ed.) 1988. Chemical Mediation of Coevolution. Academic Press, San Diego.

Turlings, T.C. J., J.H. Tumlinson, R.R. Hearth, A.T. Proveaus & R.E. Doolittle. 1991. Isolation and identification of allelochemicals that attract the larval parasitoid, *Cotesia marginiventris* (Cresson), to the microhabitat of one of its hosts. J. Chem. Ecol. 17, 2235～2251.

Vinson, S.B. 1968. Source of a substance in *Heliothis virescens* that elicits a searching response in its habitual parasite, Cardiochilus nigriceps. Ann. Entomol. Soc. Am. 61, 8～10.

Vite, J.P. & D.L. Williamson. 1970. *Thanasimus dubius* : prey perception. J. Insect Physiol. 16, 233～239.

Wang, C.Z. 1991. Behavioral and chronic effects of cotton allelochemicals on the cotton bollworm and its endoparasitoid. Doctoral Thesis, Beijing Agricultural University. (in Chinese, with English summery).

Whittaker, R.H. 1970. Communities and Ecosystems. Macmillan, N. Y.

Whittaker, R.H. & P.P. Feeny. 1971. Allelochemics: chemical interactions between species. Science 171, 757～770.

Wilson, E.O. 1970. Chemical communication within animal species. In Sondheimer, E., & J.B. Simeone (eds.) Chemical Ecology. Academic Press, N.Y.