SEMIOCHEMICALS INFLUENCING FALL ARMYWORM PARASITOID BEHAVIOR: IMPLICATIONS FOR BEHAVIORAL MANIPULATION[1]

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ABSTRACT

The existence of semiochemicals that influence the host selection behavior of several fall armyworm (*Spodoptera frugiperda* (J. E. Smith)) parasitoids has been demonstrated. These semiochemicals are from several sources and influence the behavior in different ways. Various procedures for using semiochemicals in improving the performance of parasitoids in biological control of this important pest insect are discussed.

RESUMEN

Se demuestra la existencia de las semioquímicas ("semiochemicals") que influyen la selección de hospederas de varios parasitoides del gusano cogollero, *Spodoptera frugiperda* (J. E. Smith). Estas semioquímicas son de variados orígenes e influyen el comportamiento de varias maneras. Se discuten varios procedimientos del uso de semioquímicas para mejorar la acción de parasitoides en el control biológico de este importante insecto pestilencioso.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) is a major pest of agricultural crops in the United States (Snow and Copeland 1969), causing over $300 million in damage in years of high population density (Mitchell 1979). It is a particularly challenging target for biological control. Certain aspects of the biology and ecology of the FAW, and their influence on the population dynamics of entomophagous insects, are of fundamental importance to the design of biological control strategies involving entomophagous insects.

The FAW has no diapausing mechanisms. Thus, in the United States, continuous generations occur only in South Florida and Texas(Snow and Copeland 1969). In years when weather conditions in the overwintering areas are conducive to population growth, northward migration occurs in the spring and is apparently assisted by weather fronts (Sparks 1979). This makes it difficult for entomophagous insects to keep FAW populations in check.

Another factor contributing to the complexity of FAW control is the many plants attacked by this pest. Tietz (1972) listed 68 genera of plants, many of which are weed species, that are attacked by the FAW. Corn, peanut, sorghum, and bermuda grass are favored agricultural hosts for the

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FAW (Sparks 1979). The effect of the annual row crop agroecosystems on populations of beneficial insects was discussed in a paper presented at a previous symposium (Lewis and Nordlund 1980).

The FAW does not suffer from a lack of natural enemies. Ashley (1979) listed 53 species of parasitoids which attack the FAW, not to mention numerous predators. The most frequently recovered parasitoids were *Cotesia marginiventris* (Cresson) and *Chelonus insularis* (Cresson).

From the above we see that several factors contribute to the complexity of the FAW as a target for biological control: it is not present in its entire range throughout the year but populates areas afresh though not necessarily every year; it attacks numerous host plants; it is a pest of annual row crops; and it is attacked by numerous entomophagous insects.

Thus, outside the overwintering area at least, the use of parasitoids for the control of FAW will require approaches such as periodic releases and environmental manipulations to increase the effectiveness of both naturally occurring and released entomophages. In the overwintering area, classical biological control may be effective, if a suitable entomophage can be found and imported. Encouragement of native entomophages or periodic releases of native or imported entomophages may also be effective in the overwintering area. The approaches discussed here are applicable both inside and outside the overwintering area for the establishment and encouragement of imported or native parasitoids.

The basis for behavioral manipulation with semiochemicals and techniques for their use in control of *Heliothis* spp. has recently been reviewed by Nordlund et al. (1984a). This paper reviews semiochemical-mediated behavior of parasitoids attacking the FAW and some approaches for manipulation of that behavior to improve the effectiveness of biological control programs.

SEMIOCHEMICALS AND THE BEHAVIOR OF PARASITOIDS

Over the years chemicals emanating from host or prey insects have been shown to stimulate in one way or another the host or prey selection behavior of many entomophagous insects (Nordlund et al. 1981), and parasitoids that attack the FAW are no exception. These chemicals are called kairomones (Brown et al. 1970).

Telenomus remus Nixon females, an egg parasitoid indigenous to Sarawak and New Guinea, respond to (Z)-9-tetradecene-1-ol acetate (Z-9-TDA) and (Z)-9-dodecene-1-ol acetate (Z-9-DDA) (Table 1), which are important components of the sex pheromone of the FAW (Nordlund et al. 1983). The presence of these compounds stimulates increased rates of parasitization. The accessory gland secretion of female FAW, which is apparently used to cement eggs in place (Berry 1968, Lacoco and Huebner 1980, Strand and Vinson 1982), has been shown to contain kairomones that stimulate drilling by *T. remus* (Table 2) and *C. insularis* (Vinson 1975, Nordlund unpublished data).

Kairomones from FAW larval frass, and other host produced materials, stimulate host searching and attack behavior in *C. marginiventris* (Table 3) (Loke and Ashley 1983, Dmoch et al. 1984). Dmoch et al. (1984) also demonstrated that learning by *C. marginiventris* females plays an important role in this behavior.

TABLE 1. MEAN PERCENTAGE PARASITIZATION OF *Spodoptera frugiperda* EGG MASSES BY FEMALE *Telenomus remus* ON PANS OF 'PINK EYED PURPLE HULL' COWPEAS, IN A GREENHOUSE, IN RESPONSE TO TREATMENTS OF *S. frugiperda* FEMALE ABDOMINAL TIP EXTRACT OR SPECIFIC CHEMICALS FOUND IN TIPS.[1]

Treatment	Replications	Mean percentage parasitization[2]	
		Treated	Control
Tip extract[3]	30	75.5 (±2.1)	62.2 (±2.5)
Z-9-TDA[4]	30	43.3 (±2.3)	28.9 (±1.9)
Z-9-DDA[5]	15	49.6 (±2.8)	35.6 (±2.7)

[1]From Nordlund et al. 1983.
[2]Means (± S. E.) for each test are significantly different ($P<0.5$).
[3]0.5 female equivalents/cotton role.
[4]0.5 μg/cotton roll.
[5]0.5 μg/cotton roll.

Chemicals from plants also influence the host selection behavior of parasitoids. These chemicals, termed synomones by Nordlund and Lewis (1976), are known to play important roles in the host habitat location behavior of various parasitoids (Vinson 1981). Nordlund et al. (1948b) found that *Trichogramma pretiosum* Riley females respond positively to some plant species but not to others. Synomones from corn and tomato plants stimulate increased rates of parasitization by *T. remus* (Table 4) in the laboratory. Synomones also influence the behavior of *C. marginiventris* (Loke et al. 1983, Dmoch et al. 1984). Synomones may be useful in simulating a preferred habitat for some FAW parasitoids, and thereby contribute to the suppression in key target areas.

APPROACHES FOR UTILIZATION OF SEMIOCHEMICALS

Successful releases of parasitoids, whether inoculative or inundative, require that the released organism become active and effective in the target

TABLE 2. THE NUMBER OF *Telenomus remus* FEMALES REJECTING, EXAMINING, OR ACCEPTING GLASS BEADS TREATED WITH ACCESSORY GLAND MATERIAL (AGM) FROM *Spodoptera frugiperda* OR *Heliothis zea* MOTHS.

Accessory gland material	Number of parasitoids responding		
	Rejection	Examination	Acceptance
S. frugiperda[1]			
Treated	5	5	30
Control	40	0	0
H. zea[2]			
Treated	33	6	1
Control	34	6	0

[1]$\chi^2=62.22$, df=2, $\alpha=0.0001$.
[2]$\chi^2=1.015$, df=2, $\alpha=0.6020$.

TABLE 3. COMPARATIVE RESPONSES OF FEMALE *Cotesia marginiventris* TO ANTENNAL TOUCH WITH HOST LARVAE BEFORE AND AFTER INDICATED EXPERIENCE.[1]

Age of parasitoid (days)	History of experience	% response[2, 3] Inexperienced Excitement	Inexperienced Attack	Experienced Excitement	Experienced Attack
1-2	1st & 2nd instar larvae	93.3a	1.7c	46.7b	48.3b
1-2	Mature host larvae	91.7a	0.0c	56.7b	38.3b
3-4	1st & 2nd instar larvae	90.0a	0.0c	53.3b	41.7b
3-4	1st & 2nd instar larvae[4]	93.3a	1.7b	36.7b	57.7c
2-4	Fresh host larval frass (corn diet)	50.0a	5.0c	73.3b	15.0c
2-4	Mature host hemolymph	90.0a	8.3c	60.0b	36.7b
2-4	Host larvae exuviae (varying instars)	81.7a	1.7b	53.3b	21.0c
2-4	Hexane body washes (1st & 2nd instar larvae)	88.3a	0.0b	85.0a	6.7b

[1]From Dmoch et al. 1984.
[2]Results of 6 replications.
[3]Means in the same horizontal rows followed by different letters are significantly different ($P<0.05$) as determined by Duncan's multiple range test.
[4]Provided 18-h contact rather than the usual 3 h.

area. However, the natural response of adult insects when released is to escape. This escape response can drastically reduce the effectiveness of any release effort. Semiochemicals can be used to stimulate search behavior in the parasitoid immediately before release to reduce or eliminate the escape response (Gross et al. 1975, Loke and Ashley 1984).

In order to elicit and maintain host searching activity in a parasitoid, stimuli indicating the presence of hosts, at a sufficiently high density, must be present. It generally appears that the populations of pest insects that will maintain an effective parasitoid population are higher than what we consider to be an economically damaging threshold (Knipling and McGuire 1968). Maintenance of effective parasitoid populations can be enhanced if we simulate a high host population density by proper treatment of the

TABLE 4. MEAN PERCENTAGE PARASITIZATION OF *Spodoptera frugiperda* EGG MASSES BY *Telenomus remus* FEMALES ON PANS OF 'PINK EYE PURPLE HULL' COWPEAS, IN A GREENHOUSE, IN RESPONSE TO TREATMENTS OF PLANT EXTRACTS.[1]

Extract	Percent parasitization[2]
Corn	27.2 (±2.0) a
Tomato	23.4 (±2.2) a
Control	13.6 (±3.1) b

[1]Means (± S. E.) from 9 replications.
[2]Means followed by different letters are significantly different ($P<0.05$) as determined by Duncan's multiple range test.

plants with semiochemicals (Gross 1981). The retention and effectiveness of released or naturally occurring beneficial insects may thereby be significantly increased. Though *T. remus* did not become established in south Florida (Waddill and Whitcomb 1982) it may be a suitable candidate for inundative release programs for the FAW because it can be easily reared on several host species. The fact that *T. remus* is stimulated to search for hosts by components of the sex pheromone of the FAW indicates that it possibly could be used in conjunction with mating disruption programs that rely on this pheromone.

Basic to any parasitoid relase program is an effective rearing program. Here again, semiochemicals can play a role. Parasitoids are generally stimulated to attack and oviposit by kairomones. This can be particularly useful in in-vitro rearing techniques and may also increase the effectiveness of in-vivo rearing techniques. Nettles et al. (1982) found that he could stimulate *Trichogramma* spp. to oviposit in artificial wax eggs with potassium chloride and magnesium sulfate, and was able to obtain several hundred *Trichogramma* eggs from a single artificial egg. Similar kairomones can be expected for parasitoids of FAW and should be a component of our research efforts. Nordlund et al. (1976) found that *T. pretiosum* females lived longer, produced more progeny, and parasitized more eggs when held on a substrate that had been treated with an extract of *Heliothis zea* Boddie moth scales.

Discussion

The fall armyworm is a unique challenge to biological control specialists, and successful control of populations of this pest outside the overwintering zone will require the use of augmentative approaches that increase the size and effectiveness of parasitoid populations in response to FAW infestations. This means a heavy reliance on inundative or inoculative releases of parasitoids in infested areas and/or the use of environmental manipulation to increase the effectiveness of released and naturally occurring parasitoids. The effectiveness of released or naturally occurring parasitoids can be improved by the proper use of semiochemicals. Kairomones can be used to stimulate a host seeking behavior in the parasitoids before release. Kairomones and/or synomones can be applied in the field to simulate a high host population and suitable habitat, thus increasing the effectiveness of the parasitoids.

Releasing parasitoids requires an efficient mass rearing program. Here, too, semiochemicals can be useful, in both in-vitro and in-vivo rearing techniques.

Considerable research remains to be done before any of these approaches can become part of biological control programs. Considerable preliminary information already has been accumulated and research in this area is continuing.

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THE USE OF OVIPOSITION ON ARTIFICIAL SUBSTRATES AS A SURVEY TOOL FOR THE FALL ARMYWORM

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ABSTRACT

Oviposition by the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), on red vinyl flags in the field afforded relatively efficient collection of egg masses and was correlated with oviposition on surrounding vegetation. Monitoring such oviposition on flags in sweet corn allowed anticipation of a population "boom." The use of oviposition on objects placed in the field as a sampling methd for fall armyworm is critically evaluated.

RESUMEN

La oviposición del gusano cogollero, *Spodoptera frugiperda* (J. E. Smith), en el campo sobre banderas rojas de vinilo rindió una colección relativamente eficiente de masas de huevos, y éstas fueron correlacionadas a la oviposición