BIONOMICS AND POPULATION GROWTH STATISTICS OF *CYRTOMENUS BERGI* (HEMIPTERA: CYDNIDAE) ON DIFFERENT HOST PLANTS

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ABSTRACT

Cyrtomenus bergi Froeschner (Hemiptera: Cydnidae) is a polyphagous subterranean burrower bug reported on various crops and weeds in the field. Bionomics and population growth statistics of *C. bergi* while feeding on peanut (*Arachis hypogaea* L.), pinto peanut (*Arachis pintoi*, Krapovickas et Gregory), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* [L.] Moench), welsh onion (*Allium fistulosum* L.),and sweet and bitter cassava (*Manihot esculenta* Crantz) were calculated from development time, survival of immature stages, and reproduction and female longevity under laboratory conditions. Free-choice host plant selection among peanut, maize and sweet cassava was recorded with separate rearings of *C. bergi* from the different hosts. Optimal performance of *C. bergi* as measured by fecundity, survival, and intrinsic rate of population increase occurred on peanut and pinto peanut followed by maize. Sweet cassava, sorghum, and welsh onion were not favorable hosts, and *C. bergi* was unable to complete its life cycle on bitter cassava. In the free-choice test, insects reared on peanut and maize prior to the experiments were less active in their search for food, whereas insects reared on cassava prior to the experiment showed a clear preference for peanut and maize over cassava. Our results show that *C. bergi* is highly polyphagous, however, some host plants are strongly preferred over others. Cassava is not a preferred host and weeds in and around the cassava field may serve as alternative host plants that could maintain populations of *C. bergi* in cassava.

Key Words: Soil pest, cassava, maize, peanut, welsh onion, sorghum, *Cyrtomenus bergi*, Hemiptera

RESUMEN

Cyrtomenus bergi Froeschner (Hemiptera: Cydnidae) es un insecto barrenador subterráneo polífago que ha sido reportado en diversos cultivos y malezas en el campo. La bionomía y las estadísticas de crecimiento poblacional de *C. bergi*, mientras se alimentaba de maní (*Arachis hypogaea* L.), maní forrajero (*Arachis pintoi*, Krapovickas et Gregory), maíz (*Zea mays* L.), sorgo (*Sorghum bicolor* [L.] Moench), cebolleta (*Allium fistulosum* L.), yuca dulce y amarga (*Manihot esculenta* Crantz), se calcularon a partir de los datos sobre duración del desarrollo y supervivencia de las etapas inmaduras, reproducción y longevidad de las hembras en condiciones de laboratorio. Se registró la selección de plantas hospedantes en un ensayo de libre eleccin entre el maní, el maíz y la yuca dulce, empleando crías separadas de *C. bergi* de los diferentes hospedantes. Con base en los resultados de fecundidad, la supervivencia y la tasa intrínseca del aumento de población, el comportamiento óptimo de *C. bergi* se presentó en maní y en maní forrajero, seguido del maíz. La yuca dulce, el sorgo y la cebolleta no resultaron ser hospedantes favorables y *C. bergi* no pudo completar su ciclo de vida en la yuca amarga, En el ensayo de libre elección, los insectos criados en el maní y el maíz antes de los experimentos resultaron ser menos activos en la búsqueda de alimento, mientras que los insectos criados en la yuca antes del experimento mostraron una clara preferencia por el maní y el maíz respecto a la yuca. Los resultados indican que *C. bergi* es altamente polífago; sin embargo, este insecto muestra mayor preferencia por algunas plantas hospedantes que por otras. La yuca no muestra ser una planta hospedante preferida y malezas dentro y alrededor del cultivo de yucca pueda servir como planta hospedante alternativa manteniendo la población de *C. bergi* en la yuca.

Translation provided by the authors.

The subterranean burrower bug *Cyrtomenus bergi* Froeschner (Hemiptera: Cydnidae) is a polyphageous pest, reported in crops such as cassava (*Manihot esculenta* Crantz), maize (*Zea Mays* L.), peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), onion (*Allium cepa* L.),

welsh onion (*Allium fistulosum* L.), sorghum (*Sorghum bicolor* [L.] Moench), African oil palm (*Elaeis guineesis* Jacq.), coffee (*Coffea arabica* L.), sugarcane (*Saccharum officinarum* L.), beans (*Phaseolus vulgaris* L.), peas *(Pisum sativum* L.), coriander (*Coriandrum sativum* L.), pastures and weeds (CIAT 1989, Cividanes et al. 1981, Lacerda 1983, Herrera 1988), and recently reported in asparagus (*Asparagus officinalis* L.) (Bellotti unpublished). *C. bergi* was first reported in welsh onion in 1974 (Higuita 1974, cited by Herrera 1988) and thereafter in maize (ICA 1980) and cassava (CIAT 1980). Since then, it has become a serious pest problem in regions throughout the neotropics (Bellotti et al. 1988).

All immature stages and the imago of *C. bergi* live in the soil. Oviposition also takes place there. Both adults and nymphs feed on roots, tubers and subterranean fruits (e.g., peanut) of the host plants leaving lesions in the plant tissue that facilitate the entrance of soil pathogens such as *Fusarium*, *Aspergillus*, *Genicularia*, and *Phytium* (CIAT 1980). On cassava, the infections appear as delimited dry rot spots (approx. 5 mm diameter) on the interior white starchy and edible parenchyma. Tissue degradation appears 12 to 24 h after feeding is initiated and is detectable when the root is peeled (García 1982). In cassava up to 85% of root damage (CIAT 1983) and up to 51% of starch reduction (CIAT 1985) can be ascribed to *C. bergi*. In maize, reddish spots appear at the feeding site and root rot and leaf chlorosis have been observed. A severe attack during early crop stages can cause wilting (King & Saunders 1984). In peanut both nymphs and adults pierce the pods and feed on the kernels. A light attack will cause delimited yellow to brownish dry rot spots (approx. 1.5 mm diameter) on the kernels of both mature and immature pods (Riis unpublished) and a severe attack can cause a complete decomposition of the harvest. Similar symptoms in peanut have been observed in Texas, USA, with the closely related Cydnidae, *Pangaeus bilineatus* Say (Smith & Pitts 1971).

It has not been possible to quantify damage due to *C. bergi* in the field in any of the reported crops apart from cassava where damage is assessed as a percentage of the parenchyma surface covered by rot spots. From a linear regression between percentage of cassava roots damaged and the number of *C. bergi* simultaneously collected at the same site during four crop cycles, Riis (1990) found 22% roots damaged when the number of *C. bergi* was close to zero (intercept, 22%), and the economic injury threshold was found to be 20-30% roots damaged (Bellotti et al. 1988).

An examination of life table parameters was conducted to obtain information on quality of a number of host plants. Experiments compare laboratory results on the development, survival, reproduction, and estimated life table parameters for *C. bergi* while feeding on several host plants. Free-choice host selection tests for ovipositing females were conducted on females with different host plant experience.

Materials and Methods

Stock Colonies

Cyrtomenus bergi was taken from stock laboratory colonies (23 ± 2°C, r.h. 65 ± 5%, L12:D12) maintained on sprouting maize and peanut, respectively, in unsterilized soil (loamy clay) kept at a moisture level approximated to the field capacity (33.5% gravimetric soil water).

Experimental Host Plants

Fecundity, survival, and development were assessed on the following host plant diets: Sprouting peanut (*Arachis hypogaea* L. cv. Tatui SM-76), pinto peanut (also called wild peanut, *Arachis pintoi*, Krapovickas et Gregory cv. Amarillo), maize (*Zea mays* L. cv. ICA V-156), and sorghum (*Sorghum bicolor* (L.) Moench cv. HW1758), root discs of a sweet cassava variety (*Manihot esculenta* Crantz cv. MCOL1468, < 100 ppm hydrogen cyanide measured), a bitter cassava variety (*Manihot esculenta*, Crantz cv. MCOL1684, ≥100 ppm hydrogen cyanide measured), and subterranean culms with primary roots of welsh onion (*Allium fistulosum* L.). Sprouting peanut, maize, and sorghum were placed in humid germination chambers 4 d before use. Cassava was harvested at the age of 7-12 months and chopped into 1 cm thick root discs. Welsh onions were bought from the local vegetable market and 3-cm culm, including primary roots, was provided to the insects.

Development Time and Survival of Immature Stages

Development time and survival of the five immature stages of *C. bergi* were assessed in a temperature and light controlled room (25 ± 1.5°C, r.h. 65 ± 5%, L12:D12). To determine the nymphal development from hatching of eggs to adult, recently emerged (<16 h) first instars from the 'maize colony' were placed individually in approximately 30 cm^3 soil (loamy clay, approx. 33% soil water content) in opaque plastic vials (55 cm^3). One hundred individuals were placed on each host plant diet. Every 2 d the plant diet was renewed and the soil of each plastic vial was searched for exuviae until all nymphs had molted to the adult stage. Mortality of each instar and the number of days required to complete each life stage were recorded. Since observations were made every 2 d, subtracting 0.5 d approximated the development time of each life stage. An analysis of variance and subsequent REGWQ grouping (SAS Institute 1988) was computed for the

development time of each instar to facilitate comparisons among host plant diets.

Reproduction and Female Longevity

Fecundity and post-teneral female longevity were assessed for each experimental host plant diet (25 ± 1.5°C, r.h. 65 ± 5%, L12:D12) with cohorts of 25-30 adult females recovered at ecdysis (<16 h after) from the 'maize colony'. This was repeated on the experimental peanut diet with insects from the 'peanut colony'. Each couple (1♀: 1♂) was placed separately in approx. 50 cm^3 soil (loamy clay, approx. 33% soil water content) in opaque plastic vials (55 cm^3). Female survival was assessed every 2 d and the food diet was replaced at the same time. Dead males were replaced with males from stock colonies. Fecundity was assessed every 2 weeks. After transferring each couple into a new plastic vial with new soil, each old soil sample, representing oviposition of two weeks, was separately poured into 20% salt solution and the eggs floated off for recovery and counting (Matteson 1966). Egg fertility (% eggs hatched) and preeclosion period were recorded from random samples of 50 eggs (four replications; total of 200 eggs) deposited by approx. 25 females at the age of 30-100 d after adult emergence when feeding on each of the host plant diets.

Statistics

From the survivorship and fertility schedules, the following bionomical statistics were calculated (Birch 1948; Carey 1993; Hulting et al. 1990).

Net reproductive rate (R_0):

$$R_0 = \sum_{x=0}^{\infty} l_x \cdot m_x \qquad (1)$$

is the average number of newborn offspring produced by an average female during one generation calculated as the sum of realized fecundity of all age x, where l_x denotes the fraction of surviving females at age x and m_x denotes the age-specific birth rate.

Intrinsic rate of increase (r_m):

$$N_t = N_0 \cdot e^{r_m \cdot t} \qquad (2)$$

is the instantaneous rate of change of population size of an exponentially growing population expressed in numbers per unit time (day^{-1}) per individual. We approximated r_m by the iterative method to the solution of the Lotka equation (Hulting et al. 1990):

$$\sum_{x=0}^{\infty} e^{-r_m x} l_x m_x = 1 \qquad (3)$$

Finite rate of increase (λ):

$$N_t = N_0 \cdot \lambda^t \qquad (4)$$

is the rate at which the population increases (geometrically) per individual per unit time (day^{-1}), i.e.,

$$\lambda = e^{r_m} \qquad (5)$$

Generation time (T) (days):

$$R_0 = 1 \cdot e^{r_m \cdot T} \qquad (6)$$

$$T = \frac{\ln R_0}{r_m} \qquad (7)$$

is the average maternal age at which offsprings are born. For an exponentially growing population of iterative offspring producers the generation time (T) can be calculated from the equation of exponential populations growth (Equation 2) by setting the initial population size to one female ($N_0 = 1$). After one generation (T), the population size is equal to the net reproductive rate ($N_t = R_0$), see equations 6 and 7.

Population doubling time (D) (days):

$$N_t = N_0 \cdot 2 \qquad (8)$$

$$\lambda^t = 2 = (e^{r_m})^t \text{ or } (e^{r_m})^D = 2 \qquad (9)$$

$$D = \ln 2 / r_m \qquad (10)$$

is the time required for the population to double which can be calculated from the equation of geometric increase (equation 4) when $^t = 2$, see equations 8, 9 and 10.

Data on development time and survival of immature stages were included in the above calculations. Calculations were based on a sex-ratio of 1:1, which has been found in fields of both peanut and welsh onion from determining the sex of a total of 1833 adult individuals at three localities (Riis unpublished). Calculations were also based on the assumption that the egg fertility of eggs deposited throughout the post-teneral female life span was constant.

An analysis of variance and subsequent REGWQ grouping (SAS Institute 1988) was accomplished for the post-teneral female longevity and the area under the m_x-curve (fecundity weighted by age) to facilitate comparisons among

host plant diets. Heterogeneity of error was addressed by transforming the data of female longevity, days$^{0.5}$, and fecundity, ln(area+1), and the null hypothesis H_o: b = 0 for Taylor's Power Law, $s^2 = a + \bar{x}^b$, was accepted for the transformed data.

Host Plant Selection

A free-choice host plant selection design was set up with ovipositing females from different host plant experience, i.e., reared on peanut, maize, and cassava, respectively, for one generation. Specially made triangular wood boxes (60 cm side length; 6 cm height) were filled with moist soil (33% soil water). A triangle consists of four sub-triangles and each sub-triangle at each corner was filled with sprouting kernels of either peanut, maize, or root discs of a sweet cassava variety 'MCOL1468', respectively (Fig. 1). Three triangular boxes were set up simultaneously. One hundred females from each of the three rearing colonies were placed in the center of the triangle-sub-triangle, which did not contain a host plant (Fig. 1). The distribution of females and oviposited eggs were assessed after 24 h by calculating the number of females recovered in each sub-triangle. Soil from each sub-triangle was separately poured in a 20% salt solution and the eggs floated off for recovery and counting (Matteson 1966). The setup was repeated seven times with new females each time.

Results

Development Time and Survival of Immature Stages

Cyrtomenus. bergi can develop on a wide range of host plants (Table 1). The nymphal development time, however, differed significantly among hosts ($P < 0.0001$) (Table 1), and ranking according to shortest development time was peanut, pinto peanut << maize, sweet cassava, sorghum << welsh onion << bitter cassava. This ranking was consistent for each of the individual nymphal stages, with exception of first and fifth instars. The development time of first instars did not differ significantly between the pinto peanut and sweet cassava hosts, neither did it differ significantly among maize, sorghum, welsh onion, and bitter cassava. The development time of the fifth instars did not differ significantly between the peanut and maize. The development time per instar increased significantly as the nymphs developed ($F = 290.8$, $df = 946$, $P < 0.0001$), however, second and third instar nymphs feeding on the peanut had shorter duration than first instars. The development time of fifth instars occupied 29-39% of the total nymphal development time. *Cyrtomenus bergi* was unable to complete its nymphal development on the bitter cassava variety MCOL1684.

Ranking according to nymphal survival was peanut, pinto peanut >> maize >> welsh onion > sweet cassava, sorghum >>bitter cassava. Almost complete survival occurred for nymphs feeding on peanut (98%), whereas all nymphs feeding on bitter cassava died prior to the fifth instar. In general, mortality was highest in the first instar and decreased with development. Relatively high mortality occurred during the fifth instar for nymphs feeding on sweet cassava (8%) and during the third instar on sorghum (9%) (Table 1).

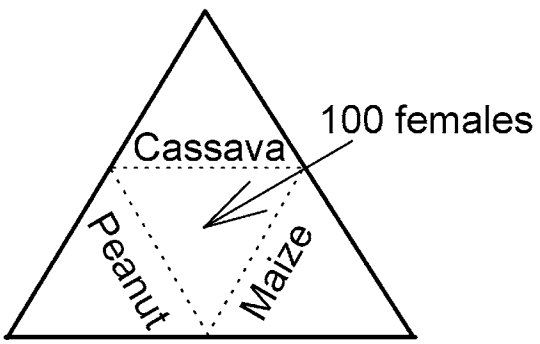

Fig. 1. Free-choice host selection design.

Female Longevity

Survivals of post-teneral females are illustrated in Fig. 2. Longevity while feeding on the different host plants differed significantly ($P < 0.0001$) (Table 2), and ranking according to increasing longevity was peanut, pinto peanut > sweet cassava > maize >> bitter cassava.

Reproduction

Eggs are deposited singly in the soil. Age-specific fecundity is illustrated in Fig. 3. Total fecundity per female differed significantly among host plants ($P < 0.0001$) (Table 2), and ranking according to increasing progeny per female was peanut, pinto peanut > maize > sweet cassava >> bitter cassava. Females reared on peanut prior to the experiment and subsequently feeding on peanut and pinto peanut showed major ovipositional peaks at 70 and 100 d after adult emergence, respectively. Additional peaks were observed three to four times during the female life span (Fig. 3a). Females reared on maize prior to the experiment and subsequently feeding on peanut showed a major ovipositional peak slightly later at approx. 125 d after adult emergence and only two additional ovipositional peaks during the female life span at approx. 250 and 335 d after adult emergence (Fig. 3b). Females reared on maize prior to the experiment and subsequently feeding on maize or sweet cassava also showed a major ovipositional peak at approx. 125 d after adult emer-

TABLE 1. DEVELOPMENT TIME (DAYS) AND MORTALITY (%) OF INSTARS OF *CYRTOMENUS BERGI* (N_0 = 100) WHILE FEEDING ON DIFFERENT HOST PLANTS.

Feeding history[1]	Experimental host plant	1st		2nd		3rd		4th		5th		Total of all immature stages	
		Days[2]	%	Days	%	Days	%	Days	%	Days	%	Days	%
Maize	Peanut	9.9 ± 0.13 a[3]	0	7.6 ± 0.17 a	0	9.3 ± 0.16 a	0	10.8 ± 0.20 a	0	24.6 ± 0.26 a	2	62.4 ± 0.48 a	2
Maize	Pinto peanut	11.0 ± 0.34 ab	0	10.1 ± 0.35 a	0	9.3 ± 0.28 a	2	12.0 ± 0.31 a	0	23.0 ± 0.31 a	0	65.3 ± 0.47 a	2
Maize	Maize	14.6 ± 0.26 c	25	15.6 ± 0.24 b	7	16.6 ± 0.27 b	7	18.2 ± 0.23 b	2	26.5 ± 0.40 ab	3	91.5 ± 0.58 b	38
Maize	Sweet cassava	12.0 ± 0.49 b	54	14.4 ± 0.82 b	0	17.2 ± 1.08 b	4	19.1 ± 1.30 b	0	28.6 ± 0.94 b	18	91.3 ± 2.83 b	64
Maize	Sorghum	14.0 ± 0.29 c	41	14.6 ± 0.40 b	2	16.0 ± 0.55 b	16	19.2 ± 0.46 b	2	27.5 ± 0.53 b	4	91.8 ± 1.14 b	64
Maize	Welsh onion	15.4 ± 0.36 c	34	19.2 ± 0.47 c	17	23.6 ± 0.47 c	11	24.5 ± 0.63 c	4	36.6 ± 0.74 c	6	119.3 ± 0.99 c	56
Maize	Bitter cassava	15.5 ± 1.35 c	83	26.7 ± 4.63 d	47	40.0 ± 3.00 d	78	—	100	—	—	—	100
ANOVA[4]		*df* = 302 *F* = 32.31****		*df* = 267 *F* = 73.15****		*df* = 239 *F* = 148.3****		*df* = 234 *F* = 108.6****		*df* = 222 *F* = 80.73****		*df* = 18 *F* = 235.9****	

[1]Feeding history prior to the experiment.
[2]Values are means standard errors. A single-classification analysis of variance was applied separately to each instar.
[3]REGWQ-grouping: Means with the same letter within the same column are not significantly different.
[4]**** denotes $P < 0.0001$.

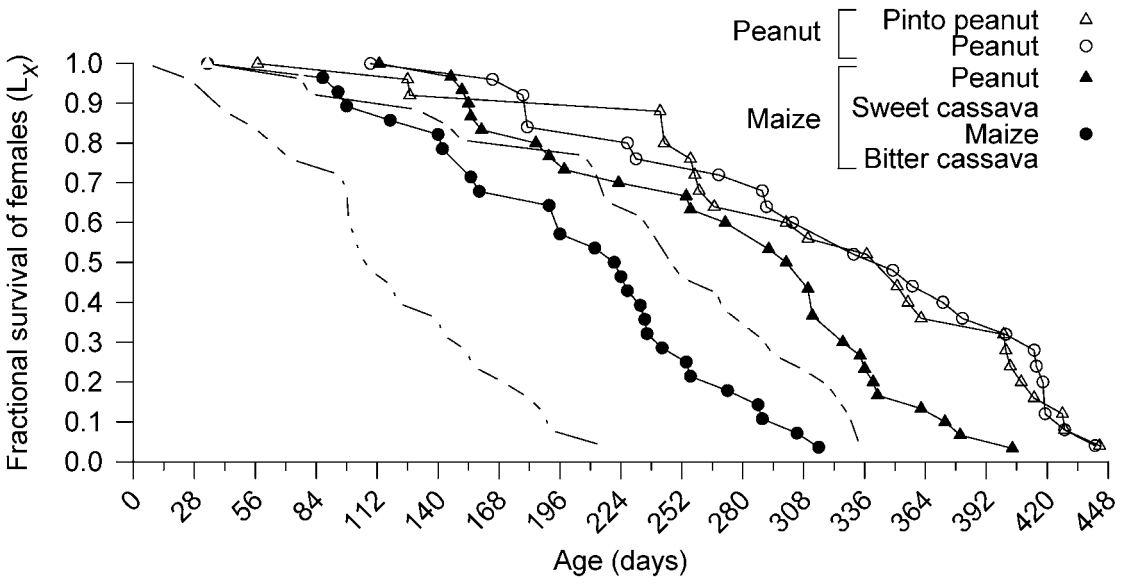

Fig. 2. Fractional age-specific survival of *Cyrtomenus bergi* females while feeding on different host plants (25°C), and after having been reared on peanut and maize, respectively, prior to the experiment.

gence, but oviposition remained high until approx. 200 d after adult emergence before oviposition eventually declined (Fig. 3b).

The ovipositional midpoint (50%) occurred at approx. 130 d after adult emergence while feeding on the peanut and maize, and at approximately 150 d after adult emergence while feeding on the sweet and bitter cassava (Table 2), but the difference was not significant ($P < 0.7339$) (Table 2). Nevertheless, when these values were calculated as a percentage of adult female life span, a significant difference among host plants was observed ($P < 0.0001$) (Table 2). Females deposited 50% of their eggs in the first 40-45% of their adult life

TABLE 2. FEMALES LONGEVITY, TOTAL FECUNDITY PER FEMALES, PERCENT OVIPOSITING FEMALES, OVIPOSITIONAL MIDPOINT (50%), AND OVIPOSITIONAL MIDPOINT AS A PERCENTAGE OF ADULT FEMALE LIFESPAN OF *CYRTOMENUS BERGI* WHILE FEEDING ON DIFFERENT HOST PLANTS.

Feeding history[1]	Experimental host plant	n[2]	Female longevity (days)[3,4]	Total fecundity per female (eggs)[3,5]	Ovipositing females	Ovipositional midpoint (50%) (days)[1]	Ovipositional midpoint as a percentage of adult female lifespan[1]
Peanut	Peanut	25	316.1 ± 19.9 a[6]	224.1 ± 24.1 a	100%	127.4 ± 11.5 a	39.7% ± 2.0 a
Peanut	Pinto peanut	25	310.9 ± 20.6 a	252.4 ± 31.7 a	100%	133.7 ± 12.0 a	45.1% ± 3.4 a
Maize	Peanut	30	270.3 ± 15.0 ab	164.0 ± 20.7 ab	97%	136.2 ± 8.9 a	50.3% ± 1.8 ab
Maize	Maize	28	199.1 ± 13.6 c	93.0 ± 13.4 bc	93%	131.1 ± 9.3 a	64.6% ± 3.1 ab
Maize	Sweet cassava	26	232.2 ± 16.5 bc	52.3 ± 9.5 c	88%	150.3 ± 9.9 a	62.5% ± 3.9 ab
Maize	Bitter cassava	25	111.7 ± 11.0 d	1.3 ± 1.3 d	4%	153.0 ± 0.0 a	70.8% ± 0.0 b
Maize	Sorghum	—	—	—	—	—	—
Maize	Welsh onion	—	—	—	—	—	—
ANOVA[7]			*df* =153 *F* = 21.37****	*df* = 153 *F* = 67.31****		*df* = 123 *F* = 0.56 NS	*df* = 123 *F* = 11.47****

[1]Feeding history prior to the experiment.
[2]n denotes sample size.
[3]Values are means ± standard errors.
[4]Single-classification analysis of variance was run on the number of days of longevity transformed as days$^{0.5}$;
[5]Single-classification analysis of variance was run on the area under the m_x-curves transformed as ln(area+1);
[6]REGWQ-grouping: Means with the same letter within the same column are not significantly different.
[7]**** denotes P< 0.0001; NS denotes not significant.

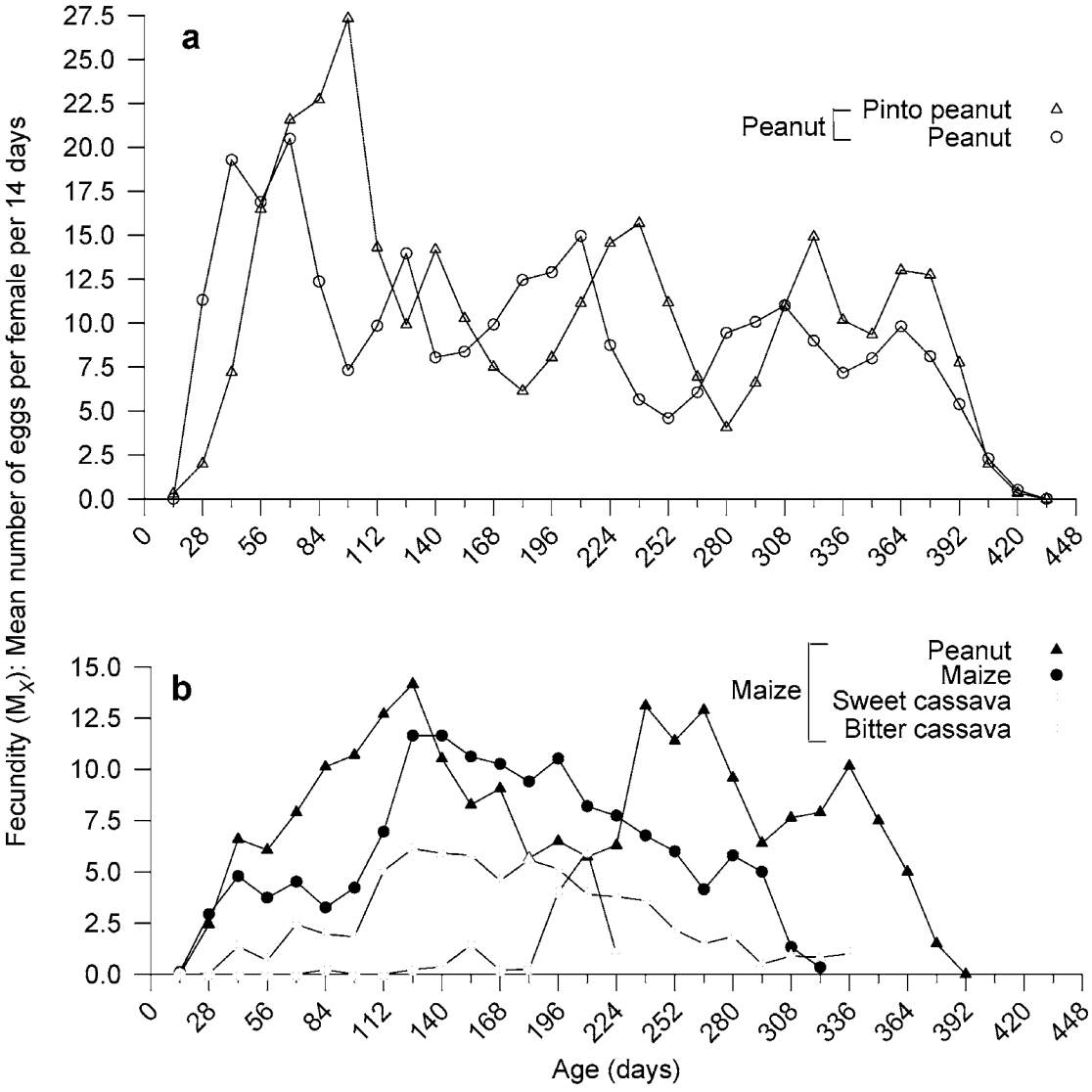

Fig. 3. Age-specific fecundity of *Cyrtomenus bergi* while feeding on different host plants (25°C), and after having been reared on peanut (a) and maize (b), respectively, prior to the experiment.

span when feeding on the peanut both before and during the experiment. When reared on maize prior to the experiment, females deposited 50% of their eggs within the first 50-65% of their life span while feeding on peanut, maize, and sweet cassava and within the first 70% of their life span while feeding on bitter cassava.

The pre-oviposition period ranged between 14-28 d on all hosts with exception of the bitter cassava, where only one female deposited eggs after 84 pre-ovipositional days (Table 3). Mean egg fertility was 90.5% and mean egg eclosion time was 13.5 d. Neither egg eclosion time nor mean egg fertility differed significantly among the host plants.

Population Growth Statistics

All life-table parameters with exception of egg fertility and eclosion time were found to be dependant on the host plant (Table 3). Net reproductive rate (R_0) was greatest for pinto peanut followed by peanut, and declined considerably for maize and sweet cassava. The intrinsic rate of increase (r_m) was significantly higher for females feeding on peanut, after pre-experimental rearing on peanut (Table 3) than after pre-experimental rearing on maize. For females reared on maize, the ranking according to increasing r_m-value was peanut >> maize >> sweet cassava. The values of doubling time (D) and mean generation time (T) decreased

TABLE 3. DEMOGRAPHIC PARAMETERS FOR *CYRTOMENUS BERGI* FEEDING ON DIFFERENT HOST PLANTS AT 25ºC.

Feeding history[1]	Experimental host plant	n[2]	Net reproductive rate (R_0)[3]	Intrinsic rate of increase (r_m)/day[4]	Finite rate of increase (λ)/day[5]	Doubling time (D) (days)[5]	Mean generation time (T) (days)[5]
Peanut	Peanut	25	98.8 ± 10.6	0.0318 ± 0.0009 a[6]	1.0323	22.0	145
Peanut	Pinto peanut	25	111.2 ± 14.0	0.0290 ± 0.0011 a	1.0294	23.8	162
Maize	Peanut	30	72.3 ± 9.2	0.0250 ± 0.0009 b	1.0254	27.6	170
Maize	Maize	28	25.9 ± 4.6	0.0154 ± 0.0015 c	1.0155	44.8	210
Maize	Sweet cassava	26	8.5 ± 1.5	0.0087 ± 0.0009 d	1.0088	77.7	240
Maize	Bitter cassava	25	—	—	—	—	—
Maize	Sorghum	—	—	—	—	—	—
Maize	Welsh onion	—	—	—	—	—	—

[1]Feeding history prior to the experiment.
[2]n denotes sample size.
[3]Values of the net reproductive rate are means ± standard errors.
[4]Values of the intrinsic rate of increase are based on estimates of r_m ± standard error of Jackknife estimates (Carey 1993).
[5]Values of the finite rate of increase, doubling time and mean generation time are means.
[6]Means that lie within the 95% confidence interval of other means have the same letter.

as the intrinsic rate of increase (r_m) increased (Table 3).

Host Selection

Within a time frame of 24 h, higher numbers of ovipositing females, which were reared on peanut ($P < 0.0001$) and maize ($P < 0.0018$), remained at the release point, where no host plant was available, rather than moving to spaces with hosts (Table 4). On the contrary, females reared on sweet cassava preferred peanut and maize over sweet cassava ($P < 0.0001$), and proportionally more females moved towards the two preferred hosts rather than staying at the release point with no host plants available (Table 4).

The distribution of oviposited eggs within the experimental space corresponded with the distribution of the females. Oviposition of females reared on peanut was high. Oviposition of females reared on maize and sweet cassava was low and there were no differences among hosts (Table 4).

DISCUSSION

Our results confirm that *C. bergi* is highly polyphagous. It can develop on a range of host plants from different families, but some host

TABLE 4. HOST PLANTS SELECTED BY 15-30 D OLD OVIPOSITING FEMALES OF *CYRTOMENUS BERGI* (N = 100) 24 H AFTER RELEASE IN A HOST PLANT FREE SPACE (SEE FIG. 1). THE SPECIMENS WERE TAKEN FROM THREE DIFFERENT COLONIES IN WHICH THEY FED ON PEANUT, MAIZE, AND SWEET CASSAVA, RESPECTIVELY, FOR ONE GENERATION PRIOR TO THE EXPERIMENT.

Host plant selected by *C. bergi*:	Pre-experimental colony					
	Peanut		Maize		Sweet cassava	
	Females	Eggs	Females	Eggs	Females	Eggs
Release point[1] (no host plant)	56.5 ± 10.1 a[3]	39.0 ± 9.3 a	50.3 ± 11.2 a	24.0 ± 9.1 a	20.7 ± 4.0 ab	18.8 ± 6.4 a
Peanut[2]	17.9 ± 5.0 b	10.2 ± 3.8 b	21.3 ± 5.7 b	8.7 ± 5.3 a	33.4 ± 2.1 a	7.2 ± 2.8 a
Maize[2]	16.1 ± 4.2 b	8.0 ± 2.1 b	18.3 ± 4.4 b	7.8 ± 3.7 a	32.6 ± 2.0 a	10.7 ± 3.8 a
Sweet cassava[2]	9.3 ± 2.2 b	10.7 ± 3.5 b	9.9 ± 2.1 b	10.7 ± 3.6 a	13.1 ± 3.1 b	9.8 ± 3.7 a
ANOVA[4]	df = 24 F = 12.18****	df = 24 F = 10.38****	df = 24 F = 6.77**	df = 24 F = 2.31 NS	df = 24 F = 11.21****	df = 24 F = 1.85 NS

Values are means of numbers of females located within each space ± standard errors;
Single-classification analyses of variance were applied separately to each group of host plant regime before test;
[1]Insects were released in the central 'sub-triangle-space' of a triangle;
[2]The 'sub-triangle-space' of one corner in a triangle;
[3]REGWQ-grouping: Means with the same letter within the same column are not significantly different.
[4]**** denotes P < 0.0001; ** denotes P < 0.001; NS, not significant.

plants are strongly preferred over others. Best performance of *C. bergi* measured as fecundity, survival, and intrinsic rate of population increase, occurred on peanut and pinto peanut followed by maize. Sweet cassava, sorghum, and welsh onion were not favorable hosts, and *C. bergi* was unable to complete its life cycle on bitter cassava. The computation of the intrinsic rate of increase (r_m) (day^{-1}) resulted in a clear differentiation of the host plant qualities, and also the impact of the feeding history prior to the experiment was highly significant. The intrinsic rate of increase was significantly higher for insects feeding on peanut after pre-experimental rearing on peanut than after pre-experimental rearing on maize. The development time of nymphs feeding on sweet cassava after pre-experimental rearing on maize was 91.3 d compared with 111.3 d after pre-experimental rearing on sweet cassava (García 1982).

Nymphal development was consistently completed with five instars. In general, the development time increased as the instars increased, however, on peanut the second and third instars developed faster than the first instars indicating a major plasticity of these intermediate instars.

Although the development time on maize was not significantly different from that on sweet cassava and sorghum, maize offered better host qualities than sweet cassava and sorghum due to higher survival; 62% on maize compared with 36% on sweet cassava and sorghum. In the field, Peairs and Carballo (1987) found higher numbers of *C. bergi* in maize as a monoculture and in a maize-cassava intercropping than in cassava monoculture. Unfortunately, they did not assess the damage caused by *C. bergi* to explain whether maize acts as a trap crop reducing damage to cassava intercropped with maize, or alternatively, whether the damage to cassava in the intercropping system increases due to increased population density of *C. bergi*.

The total average life spans (egg eclosion time + nymphal development time + female longevity) for *C. bergi* feeding on the two types of peanut were 360-380 d. Interestingly, the total average life span for insects feeding on maize was only 290 d compared with 324 d for insects feeding on sweet cassava after pre-experimental rearing on maize in spite of the reproduction being higher on maize than on sweet cassava. Reduced reproduction and increased longevity while feeding on cassava compared with maize demonstrates a possible physiological trade-off between reproduction and longevity consistent with the 'principle of allocation' paradigm (Pianka 1988). The increase in life span caused by dietary restriction can be explained as a consequence of lower reproduction. This response may enable *C. bergi* to adapt increased fitness when encountering favorable food supply. García (1982) found that *C. bergi* had a greater total average life span of 418 d when feeding on root discs of sweet cassava after pre-experimental rearing on cassava. However, García (1982) did not collect data on fecundity from the same females for comparison. Evidently the quality of peanut as a host plant can maintain both high reproduction and an extended longevity.

The total average fecundity when feeding on bitter cassava was almost zero; only one female out of 25 deposited eggs. The total average fecundity was twice as high when feeding on maize and three times higher when feeding on peanut compared with that of cassava. The pre-experimental rearing history had a significant impact on the fecundity; females feeding on peanut deposited 37% more eggs after pre-experimental rearing on peanut than after pre-experimental rearing on maize. The total average fecundity per host plant increased with increasing proportion of females depositing eggs.

The ovipositional midpoint as a percentage of adult female life span, however, differed significantly among hosts; the higher fecundity, the earlier in the life span the eggs were deposited resulting in a shorter mean generation time (*T*). The doubling time (D) of populations reared and feeding on peanut was twice as short as that of populations reared and feeding on maize and nearly four times shorter than the doubling time of populations feeding on sweet cassava. The daily population growth ranged from 3.2% in peanut to 1.5% in maize and 0.9% in sweet cassava.

The majority of the insects that had been reared on peanut and maize prior to the free-choice test remained in the release space where no host plant was available. On the contrary, insects reared on cassava prior to the test showed a clear preference for peanut and maize over cassava and the host plant free space where they had been released. Only females reared on peanut deposited sufficient eggs to reflect the female positioning and host selection. These results show a strong preference for peanut and maize. They also show that insects which have fed on peanut and maize are less active in their search for food; they are probably well fed and better prepared to survive in a host plant-free space or period of time. After rearing on peanut and subsequently left to starvation, Riis (unpublished) found the lethal time at 50% mortality to be 80 d for females and 74 d for males, demonstrating a strong capacity for survival in the absence of food. Unfortunately, the study did not include other host plants nor was the fecundity studied under these circumstances.

Our results show that cassava is not a preferred host to *C. bergi*, and insects fed on cassava are very active in their search for more and better food. In addition to this, Riis (1990) found that the thickness of the root peel is an obstacle to the propagation of *C. bergi*; first and second instars were unable to feed on un-peeled roots with a peel thickness greater than 2 mm, and only 3.3% of

first instars survived on roots with 1-1.5 mm thin peel. This may be one explanation to why the root apices, with thinner peel, were more frequently attacked and damaged than other parts of the root (Bellotti unpublished). In the case of cassava, we suggest that weeds in and around the cassava field may serve as alternative host plants that could maintain populations of *C. bergi* in cassava.

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INFLUENCE OF TEMPERATURE AND SOIL MOISTURE ON SOME POPULATION GROWTH PARAMETERS OF *CYRTOMENUS BERGI* (HEMIPTERA: CYDNIDAE)

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ABSTRACT

Abundance of *Cyrtomenus bergi* Froeschner has been reported regularly under moist and damp conditions. The influence of temperature and soil moisture on development time and mortality of first, third, and fifth instars, longevity and fecundity of *C. bergi* adult females, as well as hatching time and rate of eggs were determined under laboratory conditions at different temperature and soil moisture levels. Population growth is optimal around 26°C (constant temperature) and a soil moisture regime ranging from moist (field capacity) to wet soil (between field capacity and water saturation). Wet soil (~44% gravimetric soil water) promotes high mean fecundity in young adult females, reducing generation time and favoring population growth compared to that seen in moist soil (~33.5% gravimetric soil water, field capacity). The lower temperature threshold for development was 14.7°C. Neither egg hatching nor molting from fifth instars to adults occurred above 31°C. The lower soil moisture threshold for immature development was between dusty (~19% gravimetric soil water) and very dry soil (~22% gravimetric soil water) and between very dry and dry (~25.5% gravimetric soil water, wilting point) for adult female survival and oviposition. Third instars were most tolerant to extreme temperatures. These abiotic limitations to population growth together with other findings concerning host plant regime and movement in soil may explain patterns of local and regional abundance.

Key Words: Subterranean burrower bug, soil arthropod, population growth parameters, *Cyrtomenus bergi*

RESUMEN

Con cierta regularidad se ha reportado la proliferación de *Cyrtomenus bergi* Froeschner en condiciones de humedad. Se determinó, en condiciones de laboratorio, la influencia de diferenctes niveles de temperature y humedad del suleo en la duración del desarrollo y la mortalidad del primer, tercer y quinto instar ninfal, en la longevidad y en la fecundidad de hembras adultas de *C. bergi*, así como en el momento de eclosión y la tasa de eclosión de los huevos. El crecimiento de la población es óptimo alrededor de 26°C (temperatura constante) y un régimen de humedad del suelo que fluctúa entre suelo húmedo (capacidad de campo) y suelo saturado (entre la capacidad de campo y saturación hídrica). Suelo húmedo (~44% de agua gravimétrica del suelo) aumenta la fecundidad promedia de hembras adultas jovenes reduciendo el tiempo de procreación y favoreciendo el crecimiento de la población en el suelo saturado en comparación con el suelo húmedo (~33.5% de agua gravimétrica del suelo, capacidad de campo). El umbral de temperatura más baja para el dasarrollo fue 14.7°C. A partir de los 31°C no hubo eclosión de huevos ni muda del quinto instar a adulto. El umbral de humedad del suelo más bajo para el desarrollo de los estadios inmaduros fue entre suelo polvoriento (~19% de agua gravimétrica del suelo) y suelo muy seco (~22% de agua gravimétrica del suelo) y entre suelo muy seco y suelo seco (~25.5% de agua gravimétrica del suelo, punto de marchitez) para la superviviencia de hembras adultas y la oviposición. El tercer instar presentó la mayor tolerancia frente a las temperaturas extremas. Estas limitaciones abióticas para el crecimiento de la pobación, aunados a otros resultados en cuanto al régimen y movimiento de plantas hospedantes en el suelo pueden explicar los modelos de proliferación local y regional.

Translation provided by the authors.

Cyrtomenus bergi Froeschner is a subterranean burrower bug and polyphagous pest reported on cassava (*Manihot esculenta* Crantz), maize (*Zea Mays* L.), peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), sorghum (*Sorghum bicolor* [L.] Moench), welsh onion (*Allium fistulosum* L.), African oil palm (*Elaeis guineensis* Jacq.), coffee (*Coffea* spp. L.), sugarcane (*Saccharum* spp. L.), pasture grasses, and weeds (Bellotti & García 1983; Lacerda 1983; Herrera 1988). Since the first

description of *C. bergi* as a pest on cassava (CIAT 1980), it has become a serious problem throughout the neo-tropics (Arias & Bellotti 1985).

C. bergi feeds on roots, tubers, or subterranean fruits (e.g., peanuts) of host plants. The bug injects its stylet in the subterranean plant tissue leaving lesions that facilitate the entrance of soil pathogens such as *Fusarium*, *Aspergillus*, *Genicularia*, and *Pythium* (CIAT 1980). On peanut kernels, lesions appear as delimited dry rot spots (approximately 1-2 mm diameter), and a heavy attack can cause complete deterioration of the kernels (personal observation). On cassava roots, tissue degradation (approximately 5 mm diameter) appears on the interior white starchy and edible parenchyma 12-24 h after feeding is initiated (García 1982).

All immature stages and the imago of *C. bergi* live in the soil. Oviposition also takes place there. The five instars and the adults feed on the same host spectrum leaving similar damage symptoms. Riis et al. (2005) found that *C. bergi* has a total average life span of 380 d when feeding on peanut, 324 d when feeding on sweet cassava and 290 d when feeding on maize (25°C and 65 ± 5% RH).

The data base of *C. bergi* collections at Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, includes collections from the northwestern part of the South American continent, with the majority (62%) reported from altitudes of 1000-1700 meters above sea level with average monthly rainfall above 85 mm throughout the year, and average monthly temperature ranges from 20-21°C (unpublished). Several reports indicate a relation between abundance of *C. bergi* and humid conditions. Clavijo (1981) showed an increased number of *C. bergi* in light traps during periods of high precipitation, and Riis (1990) observed increased cassava root damage due to *C. bergi* following increased precipitation. Cividanes et al. (1981) also related fluctuations of *C. bergi* captures to weather factors, and King and Saunders (1984) state that *C. bergi* is more frequently found under damp conditions. Highland and Lummus (1986) suggest that soil moisture and rainfall are crucial factors increasing populations of the burrower bug *Pangaeus bilineatus* (Say), also Cydnidae.

A laboratory experiment was conducted to determine the influence of temperature and soil moisture on development time and mortality of first, third, and fifth instars, longevity and fecundity of *C. bergi* adult females as well as hatching time and hatching rate of eggs. Since *C. bergi* has a very long lifecycle, second and fourth instars were left out of the experiment to reduce time.

Materials and Methods

Stock Colony

Cyrtomenus bergi was taken from a stock laboratory colony (23 ± 2°C, 65 ± 5% RH, 12 h light) maintained on germinating seeds of peanuts, *Arachis hypogaea* L. (variety 'Tatui SM-76') in unsterilized topsoil (loamy clay) kept at a moisture level approximated to the field capacity (33.5% gravimetric soil water). The colony originated from a fallow field at La Bella, Rereira (Province of Risaralda), Colombia and had been maintained in culture for one generation.

Experimental Soil

Soil of the Ah-horizon, 0-18 cm, from the CIAT Field Research Station at Santander de Quilichao in southern Colombia was used. The soil is described as a loamy clay with high content of organic matter (16.4 kg organic C/m^3) (Reining 1992) and pH ranging 4.0-5.2 (Riis 1990). The soil was passed through an M-4 hammer mill shredder (Lindig Mfg Corp., St. Paul, MN) to assure homogeneous water penetration of soil when irrigated in the laboratory.

Water retention characteristics of the experimental soil were determined on air-dried soil samples. Water content was measured at saturation (0 bar), field capacity (0.33 bar), wilting point (15 bar), and hygroscopic moisture (>32 bar) with a pressure plate apparatus (Soil Moisture Corp., Goleta, CA). The water-saturated samples were weighed and placed in plastic rings on porous ceramic plates, permeable to water. Samples were weighed when the state of equilibrium was reached, oven dried for 24 h at 105°C and reweighed. This was repeated three times for each sample. Water contents were calculated at the different pressures (Richards 1965; Scheffer & Schachtschabel 1989). A retention curve for this experimental homogenized soil could not be calculated, since we could not approximate empirical constants that affect the shape of the retention curve (Genuchten et al. 1991).

The experimental soil was desiccated at 60°C for 72 h. Subsequently, soil was placed in plastic containers, weighed, and irrigated while placed on a scale until the experimental soil water content was reached. The irrigated soil was left in closed containers for 48 h prior to use. Before use, three soil samples were taken to reconfirm the water content by weighing, drying (105°C, 24 h), and weighing again. After exposure to the bugs for 2 d (immature stages) and one week (adults), respectively, three soil samples were taken from each experimental temperature and moisture combination to record changes in soil water content during the experimental time.

Experimental Temperature Levels

Egg eclosion time and rate as well as development time and mortality of first, third, and fifth instars were assessed in temperature controlled incubators (65 ± 5% RH, 12 h light) at moisture levels that approximated wilting point (25.9% gravimetric soil water) and field capacity (33.5%

gravimetric soil water), respectively, and at the following constant temperatures (±1.5°C): 13°C, 18°C, 21°C, 23°C, 25°C, 28°C, and 31°C. Fecundity and longevity of post-teneral females of *C. bergi* were assessed under similar conditions, but only at 13°C, 21°C, 25°C, and 31°C.

Experimental Soil Moisture Levels

Eclosion time and rate of eggs, development time and mortality of first, third, and fifth instars as well as fecundity and longevity of post-teneral females of *C. bergi* were assessed in a temperature and light controlled incubator, 25 ± 1.5°C, 65 ± 5% RH, 12 h light, at the following approximated soil moisture levels of gravimetric soil water: 19.0% (dusty), 22.0% (very dry), 25.9% (dry, wilting point), 33.5% (moist, field capacity), 44.0% (wet), and 60.0%, (water saturated). The soil water content of the experimental soil was measured immediately before and after use.

Experimental Diet

The bugs fed on peanut kernels of which embryos had been removed to avoid water-consuming germination. The peanuts were wrapped in Parafilm® to avoid rapid deterioration.

Development Time and Mortality of Immature Stages

For the determination of the egg hatching time and rate, recently deposited eggs (<16 h) were recovered from soil exposed to adults by searching the soil carefully with a fine paintbrush. Each of four non-simultaneous replications comprised 50 eggs placed in groups of 25 in each of two 55-cm^2 opaque plastic vials with approximately 30 cm^3 of soil of the experimental moisture level. Egg hatch was observed daily beyond 7 d after oviposition and soil also was replaced daily. Hatching time and rate (percentage) were recorded.

Development time and mortality of first, third, and fifth instars were determined as follows: Recently emerged first instars (<16 h) were recovered from eggs placed on moist filter paper. Third and fifth instars were recovered at ecdysis (<16 h hereafter) from separate stock colonies exclusively containing second and fourth instars, respectively. Nymphs were placed individually in approximately 30 cm^3 of soil of each of the experimental moisture level in opaque plastic vials (55 cm^3 volume). Each of four non-simultaneous replications comprised 20 nymphs. Every 2 d, the plant diet and soil of experimental moisture levels were renewed after the soil of each plastic-vial had been searched for exuviae from molting nymphs. Development time and percent mortality were recorded for each instar. Each insect was withdrawn from the experiment at the time of molting or death.

Optimal Temperature for Immature Development

The optimal temperature for development of each of the immature stages was found by fitting a quadratic model (Hyams 1997) to hatching time/development time weighted against temperature. The temperature corresponding with the minimum development time of the curve was recorded as the optimal temperature for development.

Lower Temperature Thresholds and Day-Degrees Required for Development of Immature Stages

Lower temperature thresholds (T_0) for development of immature stages were estimated by linear regression on the reciprocal mean development time (y) weighted against temperature (T)

$$y = \alpha + \beta T$$

and T_0 was subsequently computed as

$$T_0 = -\frac{\alpha}{\beta}$$

Development time on a day-degree (DD) time scale was computed as

$$DD = DT(T - T_0) \text{ for } T > T_0, \text{ else } DD = 0,$$

where DT denotes the observed development time (days) at the temperature T (Frazer & Gilbert, 1976).

Female Longevity and Fecundity

Fecundity and adult female longevity of 25 females were assessed at each of the aforementioned experimental temperatures and soil moisture levels. Adults were recovered at ecdysis (<16 h hereafter) from a separate stock colony exclusively containing fifth instars. One female and two males were placed in approximately 50 cm^3 soil in an opaque plastic vial (55 cm^3 volume). Adults were transferred to a new plastic vial with new soil every week, female survival was recorded and the food diet was replaced at the same time. Dead males were replaced with males from the stock colony. The number of deposited eggs was counted every two weeks by flotation in a 20% salt solution of sodium chloride (Matteson 1966).

Statistics

An analysis of variance and subsequent REGWQ grouping (SAS Institute 1988) were run separately on each of the studied immature stages on development time and mortality, on adult female longevity, and area under the m_x-curve (fecundity weighted with time) for comparison of experimental abiotic conditions. A natural logarithm transformation was used to homogenize error of female longevity and area under the

mx-curve. The transformed data were re-tested for homogeneity by use of Taylor's Power Law:

$$s^2 = a + \bar{x}^b$$

The null hypothesis H_o: b = 0 was accepted for all transformed variable confirming homogeneity of error.

Results

Experimental Soil Moisture Characteristics

The water retention characteristics of the experimental soil are given in Table 1. Changes in soil moisture level during the experimental time are listed in Table 2. Soil moisture levels differed significantly before and after exposure to immature stages (soil replaced every 2 d) and adults (soil replaced weekly) at 25°C (see rows; Table 2). With the exception of dusty soil, the soil water content was reduced significantly by increasing temperature due to evaporation (see columns; Table 2).

Development Time and Mortality of Immature Stages as a Function of Temperature

The optimal temperature for hatching of eggs was 25.7°C. The optimal temperature for development of the first instars was 28.5-29.7°C, and 26.4°C for third and fifth instars. Third instars could develop at 13°C where other stages failed (Fig. 1).

The lower temperature threshold was 14.6°C for eggs compared with 13.7°C for first and fifth instars and 11.3°C for third instars (Table 3). If we assume that the lower temperature threshold for each nymphal instar is the same at field capacity and wilting point (*cf.* Table 3), a comparison between wilting point and field capacity of the development time on a day-degree scale of each instar showed that the development times of first and third instars on a day-degree scale were significantly longer at wilting point than at field capacity ($8.67 < F < 20.76$, $df = 6$, $P < 0.0258$) (*cf.* Table 3).

Development time and mortality decreased with temperature within the temperature regime 18-25°C (Fig. 1). The highest egg hatching rate ('inverse mortality') occurred at 25°C and no hatching occurred at 31°C. The lowest mortality of first and fifth instars occurred at 25°C, and at 28°C for third instars (Fig. 1). At temperatures where egg hatching and ecdysis of nymphs occurred, mortality did not differ significantly between wilting point and field capacity.

Exceptionally long survival times occurred at the extreme temperatures. At 13°C, below the lower temperature threshold of eggs, the mean survival time of first instars until death was 24 d (SE ± 2.98) at wilting point and 35 d (SE ± 3.86) at field capacity. The mean survival time of fifth instars until death at 13°C was 230 d (SE, ± 16.6) at wilting point and 232 d (SE, ± 13.9) at field capacity. Fifth instars could not molt at 31°C and the mean survival time of fifth instars until death at 31°C was 60 d (SE, ± 2.05) at wilting point and 69 d (SE, ± 2.27) at field capacity.

Table 1. Gravimetric soil water content (%) of the experimental soil under different pressures (bar).

Soil moisture level	Bar	%
Hygroscopical moisture	>32	9.9 ± 2.76
Wilting Point (WP)	15	25.9 ± 0.17
Field Capacity (FC)	0.3	33.5 ± 0.16
Saturation	0	70.2 ± 1.01

Values are means of 3 replications ± standard errors.

Development Time and Mortality of Immature Stages as a Function of Soil Moisture

Cyrtomenus bergi developed at a wide range of soil moisture levels with the exception of dusty soil. Egg hatching did not occur in very wet soil (Fig. 2). Egg hatching time was significantly shorter (by 1 d) in moist and wet soil than that in very dry soil ($F = 2889$, $df = 18$, $P < 0.0001$), and the hatching time in dry soil did not differ from any of these. The highest egg hatching rates ('inverse mortality', Fig. 2) occurred in the moisture range from dry soil (wilting point) to moist soil (field capacity) (inclusive), and were significantly higher than those in wet soil. Hatching rates in wet soil were higher than those in very dry soil ($F = 395.9$, $df = 18$, $P < 0.0001$).

Development times of nymphs (Fig. 2) did not differ significantly above wilting point (dry soil), and these were shorter than those below wilting point ($24.76 < F < 68.16$, $df = 18$, $P < 0.0001$). At all temperature levels, the development of the first instars was slightly prolonged at wilting point compared with field capacity (*cf.* Fig. 1), but these did not differ significantly. The lowest mortality of the first instars occurred in moist soil (Fig. 2) and was significantly lower than those in very wet and very dry soil ($F = 20.38$, $df = 18$, $P < 0.0001$). The lowest mortality of third and fifth instars occurred in soil moisture regime from dry (wilting point) to wet soil (Fig. 2), which did not differ significantly, and these were lower than that in very dry soil ($32.40 < F < 57,32$, $df = 18$, $P < 0.0001$).

Female Longevity and Survival by Age as a Function of Temperature

Recorded female longevity was longest at 21°C, but did not differ significantly from those at 25°C and that at 13°C at field capacity (Fig. 3a). Female survival by age (L_x) showed little mortality until

TABLE 2. SOIL WATER CONTENT (%, GRAVIMETRIC) OF EXPERIMENTAL SOIL MOISTURE LEVELS; INITIALLY AND AFTER EXPOSURE TO *C. BERGI* AT DIFFERENT TEMPERATURES.

	Soil water content (%, gravimetric)							
							ANOVA[e]	
Soil samples taken at . . .	Dusty	Very dry	Dry (WP[a])	Moist (FC[b])	Wet	Very wet	*df*	*F*
Initially	18.7 ± 0.22 a[c]A[d]	22.0 ± 0.11 aB	25.5 ± 0.08 aC	34.3 ± 0.08 aD	44.1 ± 0.22 aE	61.2 ± 0.22 aF	2714	9263****
13°C	—	—	25.2 ± 0.11 a	33.1 ± 0.10 b	—	—		
18°C	—	—	25.1 ± 0.10 a	32.9 ± 0.08 b	—	—		
21°C	—	—	24.5 ± 0.08 b	32.3 ± 0.09 c	—	—		
23°C	—	—	24.2 ± 0.17 bc	31.7 ± 0.12 d	—	—		
25°C	18.3 ± 0.54 aA	20.5 ± 0.21 bB	24.1 ± 0.07 bcC	31.5 ± 0.28 dD	42.3 ± 0.35 bE	58.7 ± 0.27 bF	790	4326****
28°C	—	—	23.8 ± 0.24 cd	31.5 ± 0.16 d	—	—		
31°C	—	—	23.4 ± 0.12 d	30.7 ± 0.28 e	—	—		
ANOVA[e]								
df	29	366	3249	2956	305	313		
F	0.75 NS	49.02****	51.35****	104.86****	17.08****	32.33****		

Values are means ± standard errors.
[a]WP denotes approximated wilting point.
[b]FC denotes approximated field capacity.
[c]REGWQ-grouping: Means with the same lower-case letter in the same column are not significantly different.
[d]REGWQ-grouping: Means with the same capital letter in the same row are not significantly different.
[e]**** denotes $P < 0.0001$; ns, not significant.

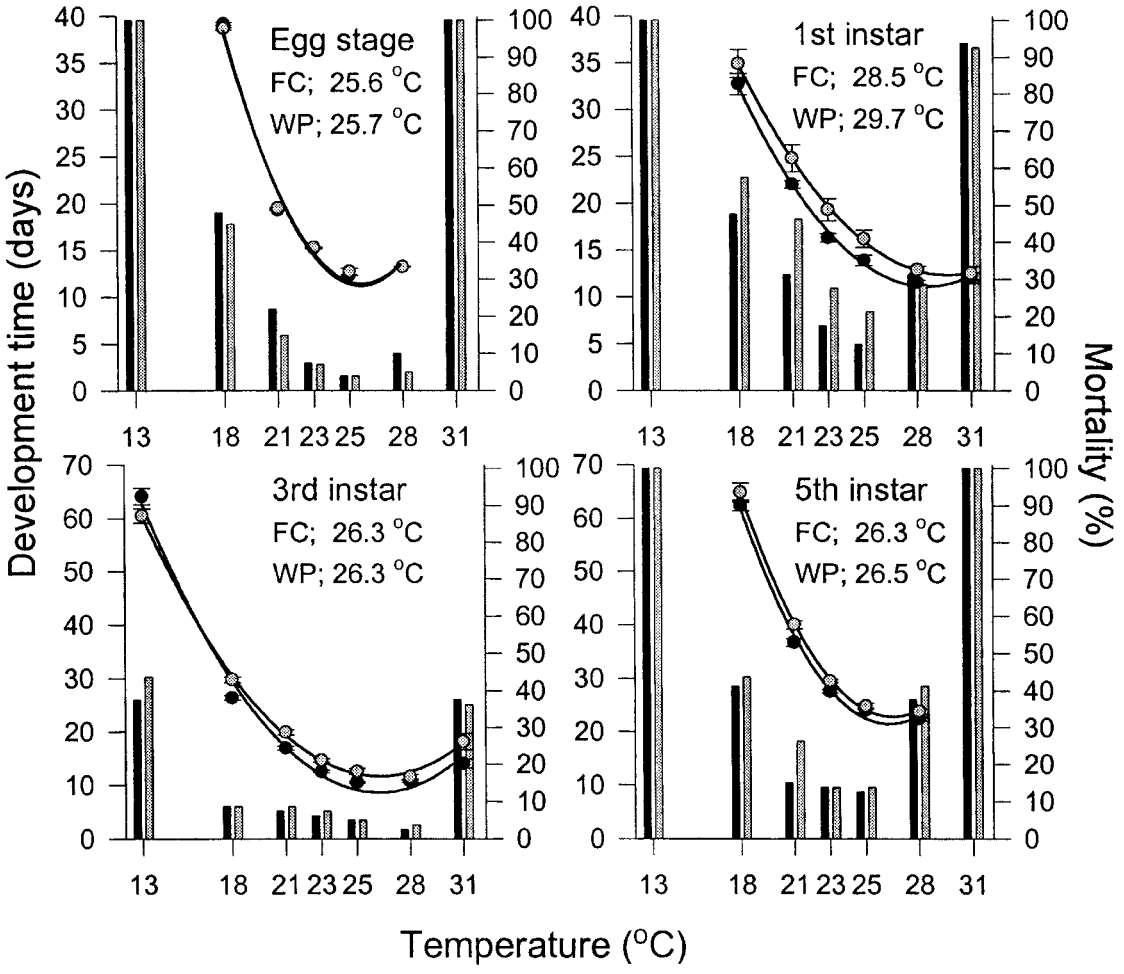

Fig. 1. Development time (dots, left axis) and mortality (bars, right axis) of some immature stages of *C. bergi* as a function of temperature and soil moisture levels approximated to field capacity (FC, black) and wilting point (WP, grey). Optimum temperatures are given at field capacity and wilting point, respectively. Dots are means and bars are percentage of 200 eggs and 80 individuals of each instar, respectively. Vertical lines denote standard errors.

approximately 180 d and then fairly steep mortality thereafter, with exception of extreme temperatures, 13°C and 31°C (Fig. 4a). Initially female survival by age (L_x) started declining more steeply at 13°C than at 31°C, both at wilting point. Nevertheless, after approximately 40 d, female survival at 13°C at wilting point declined slowly, while female survival at 31°C at wilting point declined rapidly and the population died out soon after (Fig. 4a).

Female Longevity and Survival by Age as a Function of Soil Moisture

Adult female longevity was shorter in very dry soil than at other soil moisture levels (F = 144.7, df = 120, $P < 0.0001$), which did not differ significantly from each other (Fig. 3b). Longevity did not differ significantly between field capacity and wilting point at 21-25°C. At more extreme temperatures, 13°C and 31°C, females lived longer at field capacity than at wilting point (F = 35,97, df = 192, $P < 0.0001$) (Fig. 3a).

At all soil moisture conditions female survival by age (L_x) showed little mortality until approximately 180 d and then fairly steep mortality thereafter, with exception of very dry soil in which females died out after 56 d only (Fig. 4b).

Fecundity as a Function of Temperature

Total fecundity differed significantly between temperature levels (F = 87.40, df = 192, $P <$ 0.0001). It was highest at 21°C and 25°C and did not differ significantly between these two temperature levels (Fig. 3a). All females deposited eggs at 21°C and 25°C at field capacity. Between 84-92%

TABLE 3. ESTIMATION OF LOWER TEMPERATURE THRESHOLDS (T_0) AND DEVELOPMENT TIME ON A DAY-DEGREE (*DD*) SCALE OF IMMATURE STAGES OF *C. BERGI* FEEDING ON PEANUT AT APPROXIMATED SOIL MOISTURE LEVELS OF FIELD CAPACITY (FC) AND WILTING POINT (WP), RESPECTIVELY.

Instar	Soil moisture level	*n*	Regression	r^2	*P*	T_0	*DD*[a]
Egg	FC	200	$y = -0.1160 + 0.0077T$	0.998	0.0012	14.7	126.9 ± 1.75
	WP	200	$y = -0.1092 + 0.0076T$	0.996	0.0020	14.4	132.9 ± 2.21
1	FC	80	$y = -0.0939 + 0.0069T$	0.980	0.0099	13.7	153.0 ± 4.29
	WP	80	$y = -0.0798 + 0.0061T$	0.996	0.0020	13.2	186.1 ± 5.86
3	FC	80	$y = -0.0790 + 0.0069T$	0.971	0.0021	11.4	155.5 ± 7.27
	WP	80	$y = -0.0647 + 0.0058T$	0.954	0.0043	11.1	188.1 ± 8.35
5	FC	80	$y = -0.0525 + 0.0038T$	0.997	0.0018	13.7	265.8 ± 3.08
	WP	80	$y = -0.0515 + 0.0037T$	0.997	0.0018	13.9	274.4 ± 4.00

n, sample size.
[a]Values are means ± standard errors.

females deposited eggs at 21°C and 25°C at wilting point, and at 31°C at field capacity. Only 8-12% of females deposited eggs at 31°C at wilting point and at 13°C at both wilting point and field capacity (Fig. 3a), resulting in less than 0.25 eggs per female on average. At 31°C females deposited significantly more eggs at field capacity than at wilting point.

At all soil temperature and soil moisture combinations, with mean fecundity per female >1, mean fecundity by age (M_x) showed a small peak after approximately 40-55 d and a large peak after approximately 180-210 d (Fig. 5a, b), with exception of 31°C at field capacity where only one peak occurred after 112 d (Fig. 5a).

Fecundity as a Function of Soil Moisture

Total fecundity differed between soil moisture levels ($F = 51.39$, $df = 120$, $P < 0.0001$) (Fig. 3b). Most eggs were deposited in moist (field capacity) and wet soil, and significantly fewer eggs were deposited in very wet soil. Number of eggs deposited in dry soil was intermediate and did not differ significantly from moist, wet or very wet soil. No eggs were deposited in very dry soil.

All females oviposited in moist soil (field capacity). Between 84-92% of the females oviposited in wet, very wet and dry (wilting point) soil (Fig. 3b). No females oviposited in very dry soil.

Mean fecundity by age (M_x) in wet soil was high during early age of female lifespan until its large peak at approximately 182 d, and coincided thereafter with those of moist and dry soil (Fig. 5c). Mean fecundity by age in very wet soil was inferior to those of other soil moisture levels with mean fecundity per female >1.

DISCUSSION

The optimal temperature for development of first instars was 28-29°C and 26°C for other instars. The optimal temperature for the adult stage could not be determined from the few temperature levels tested, but it is likely to be within the range of that for development. Due to the lack of parameters for second and fourth instars, we could not calculate population increase rates.

In general, the development of *C. bergi* was limited to a temperature regime ranging between 14.7°C and just below 31°C. Egg hatching could not occur at 31°C. Fifth instars lived longer at 31°C than at any other temperatures above the lower temperature threshold, but were unable to molt. At high temperature, 31°C, both fecundity and longevity were reduced compared with the 21-25°C temperature regime indicating that the upper temperature threshold was between 25 and 31°C. The third instar is the most robust instar, showing high tolerance to extreme temperature conditions.

The optimal soil moisture level for development of immature stages was moist soil (field capacity) and moist to wet soil for the adult stage. The high mean fecundity in the early age of the female lifespan in wet soil reduces the generation time and favors population growth in wet soil over moist soil. Female longevity was not reduced in very wet soil, but the number of oviposited eggs was significantly less. *Cyrtomenus bergi* did not tolerate extremely dry conditions. Very dry soil reduced longevity of adult females significantly and no eggs were deposited.

Villani and Wright (1990) speculate that heavily sclerotized soil insects should be less vulnerable to moisture loss of the cuticle under dry conditions. We, on the contrary, found that the heavily sclerotized *C. bergi* adults were more sensitive to drought than less sclerotized immature stages. The lowest soil moisture threshold for adult survival and oviposition was just below dry soil (~25.5% gravimetric soil water, wilting point), whereas the lowest soil moisture threshold for the

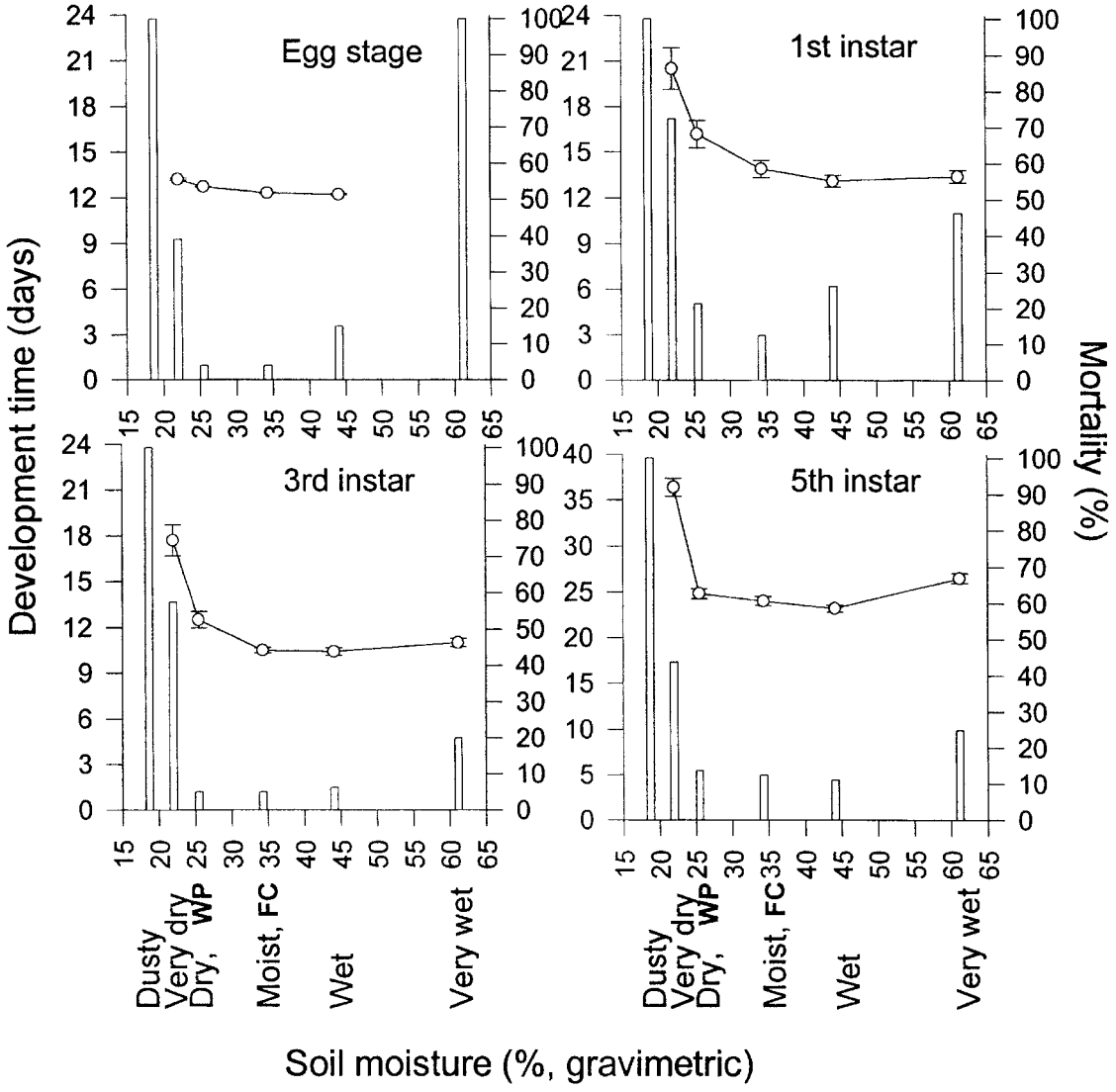

Fig. 2. Development time (dots, left axis) and mortality (bars, right axis) of some immature stages of *C. bergi* as a function of soil moisture levels and 25°C. WP and FC denote soil moisture levels approximated wilting point and field capacity, respectively. Dots are means and bars are percentage of 200 eggs and 80 individuals of each instar, respectively. Vertical lines denote standard errors.

development of immature stages was just below very dry soil (~22% gravimetric soil water). Despite the lower soil moisture threshold for immature stages compared with adults, young nymphal stages (first and third instars) did undergo some stress in dry soil as the development time on a day-degree scale was significantly longer at wilting point than at field capacity.

Although the total fecundity did not differ significantly between field capacity and wilting point within the temperature regime 21-25°C, during the initial female adult age (<150 d), we observed a higher mean fecundity at wilting point than at field capacity at 21°C opposite of what was observed at 25°C. Otherwise, soil moisture ranging from wilting point to field capacity played a significant role only for the adult stage at extreme temperatures, 13°C and 31°C. At high temperature (31°C), both total fecundity and female longevity was significantly reduced at wilting point compared to field capacity. At low temperature (13°C), longevity, but not fecundity, was significantly reduced at wilting point compared to field capacity.

Our experimental design of leaving each female individually with two males, to assure suc-

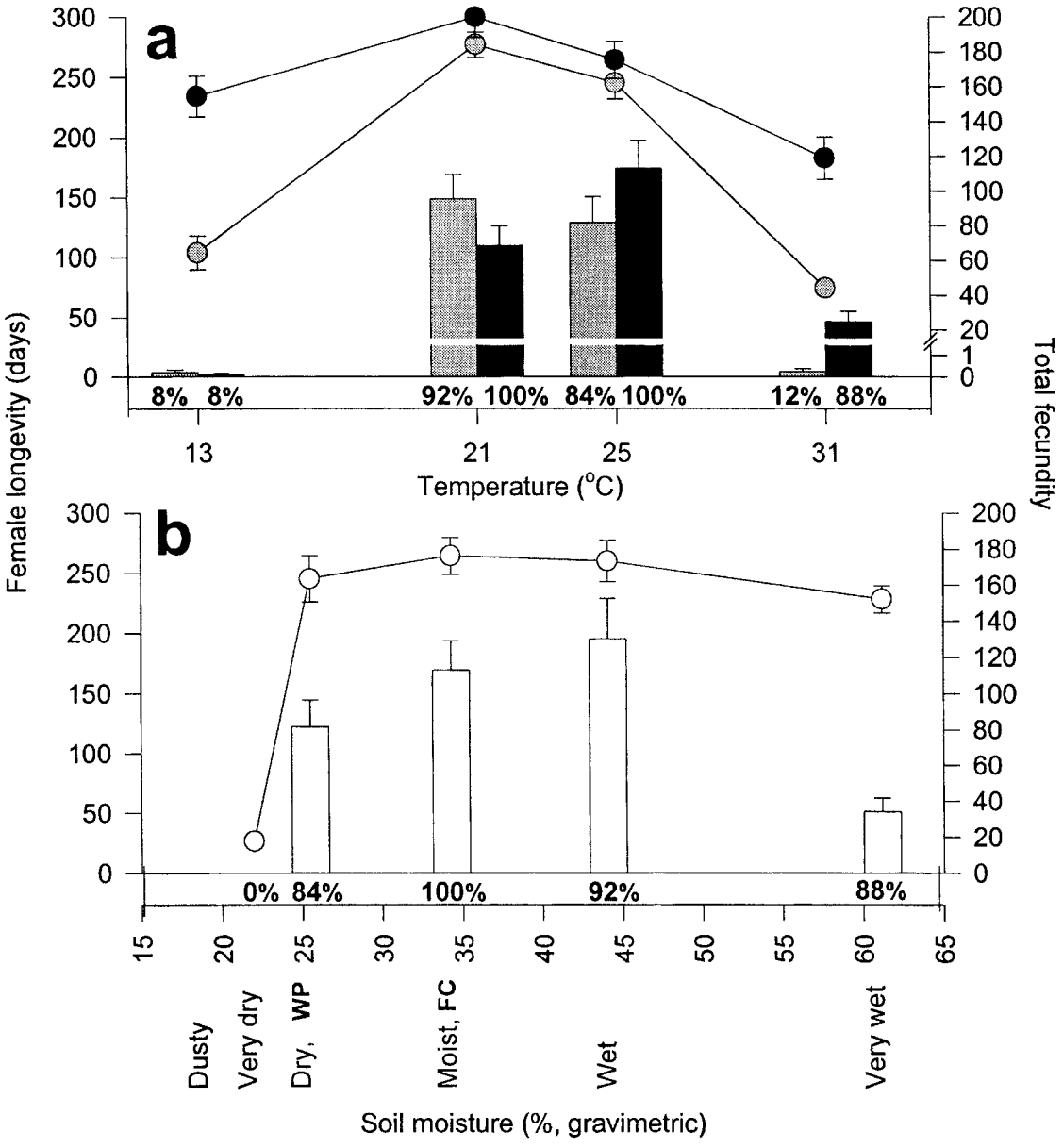

Fig. 3. Means of female longevity (dots, left axis) and total fecundity (bars, right axis) of 25 females of *C. bergi* as a function of (a) temperature at approximated field capacity (black symbols and bars) and wilting point (grey symbols and bars), and as a function of (b) soil moisture at 25°C. WP and FC denote soil moisture levels approximated wilting point and field capacity, respectively. Percentages of females ovipositing are given in bold numbers below bars. Vertical lines denote standard errors.

cessful copulation, apparently disturbed the oviposition of the female. Fewer eggs were recovered in this design compared to previous studies (Riis et al. 2005) with the same host plant and the same methodology for egg recovery, but only one male per female. The present design did not reflect the 1:1 sex ratio found in the field (Riis et al. 2005). Providing a diet of dry peanut kernels instead of germinating kernels as Riis et al. (2005) might also have influenced the ovipositional rate.

This is the first study reporting effects of soil moisture on subterranean Hemiptera. It is worth noticing that the effect of soil moisture on population growth parameters of subterranean arthropods differ remarkably among orders, for example white grubs (Cherry et al. 1990; Potter

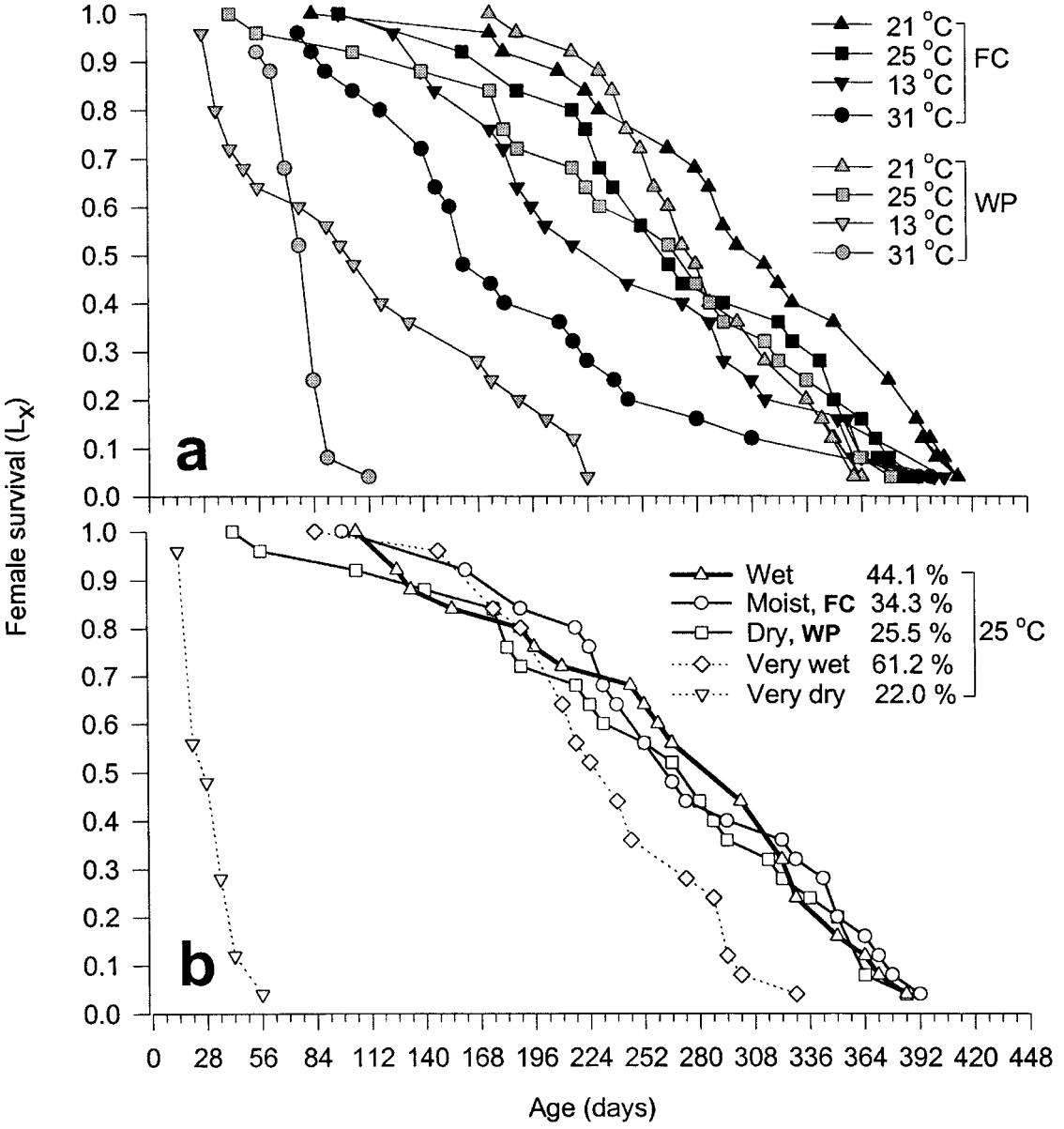

Fig. 4. Survival of 25 females of *C. bergi* during their life span as a function of (a) temperature at soil moisture levels approximated field capacity (FC, black symbols) and wiling point (WP, grey symbols), respectively, and as a function of (b) soil moisture levels (%, gravimetric) at 25°C.

1983; Règinière et al.1981), larvae of Chrysomelidae (Brust & House 1990; Lummus et al. 1983; Macdonald & Ellis 1990; Marrone & Stinner 1984), Curculionidae (Dowd & Kok 1983), and cutworms (Esbjerg 1989).

The above results, together with previous findings on active horizontal movement of *C. bergi* towards moist and wet soil, vertical emigration away from very dry soil conditions (Riis & Esbjerg 1998), and host plant regimes (Riis et al. 2005) may explain patterns of local and regional abundance.

Supported by our findings, we can conclude that *C. bergi* is well adapted for moist soil conditions, which explains its regional as well as local distribution. Moist soil conditions and a history of *C. bergi* infestation require monitoring of *C. bergi* in growers' fields and preventive treatment during early infestation.

Antagonistic soil pathogens and nematodes, which also favor moist conditions, such as the entomophilic fungi, *Metarhizium anisoplia*, and the nematodes, *Steinernema carpocapse* and *Hetero-*

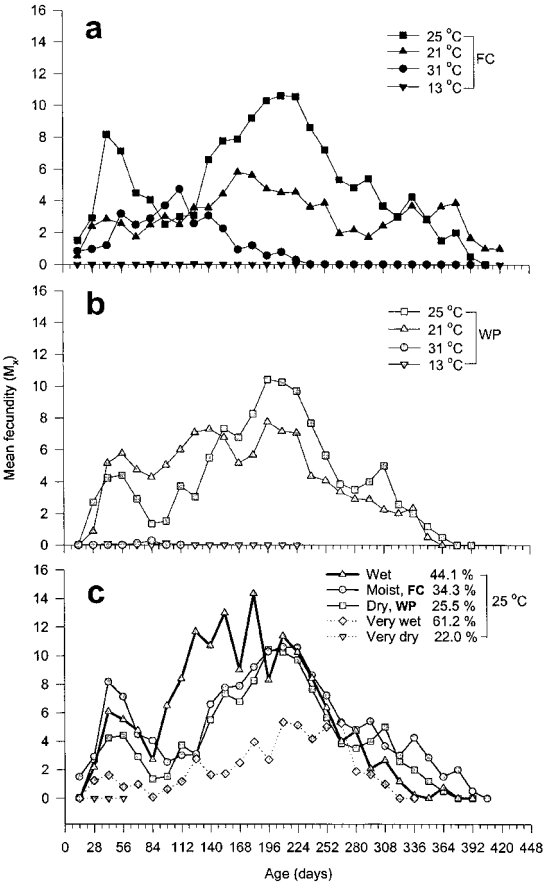

Fig. 5. Fecundity of 25 females of *C. bergi* through their life span as a function of (a) temperature at soil moisture levels approximated field capacity (FC, black symbols) and (b) wilting point (WP, grey symbols), respectively, and as a function of (c) soil moisture (%, gravimetric) at 25°C.

rhabditis bacteriophora, effectively infect *C. bergi* under laboratory conditions (Barberena 1996; Caicedo & Bellotti 1994; Sanchez 1996). Reproduction and infection rates of these differ significantly between strains depending on their climatic origin and thermal niches (Grewal et al. 1994; Kung et al. 1991; McCammon & Rath 1994). Studies for the control of *C. bergi* with such bio-agents should therefore include considerations of the influence of abiotic conditions on *C. bergi*, the bio-agent strains, and their interactions.

Acknowledgments

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TWO NEW SPECIES OF *CARISTIANUS* (HEMIPTERA: FULGOROIDEA: ACHILIDAE) FROM MAOLAN NATIONAL NATURE RESERVE IN GUIZHOU, CHINA

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ABSTRACT

Two new species of *Caristianus* Distant (Hemiptera: Fulgoroidae: Achilidae), *C. maolanensis* Chen and Li **sp. nov**. and *C. liaoi* Chen and Tsai **sp. nov**., are described from specimens collected in Maolan National Nature Reserve in Guizhou Province, China. Male genitalia of the new species are illustrated and a dorsal habitus is provided for the male of *C. maolanensis*. A key for identifying the species of *Caristianus* is included.

Key Words: *Caristianus*, new species, Achilidae, Hemiptera, Southwest China

RESUMEN

Se describen dos nuevas especies de *Caristianus* Distant (Hemiptera: Fulgoroidae: Achilidae), *C. maolanensis* Chen y Li **sp. nov**. y *C. liaoi* Chen y Tsai **sp. nov**., de especimenes recolectados en la Reserva Natural Nacional de Maolan en la Provincia de Guizhou, China. Las genitalias de los machos de estas especies nuevas son ilustratradas y se provee una ilustración del hábitus dorsal del macho de *C. maolanensis*. Se incluye una clave para identificar las especies del género *Caristianus*.

The genus *Caristianus* was established by Distant (1916) based on specimens of *C. indicus* Distant from Ceylon. Ten species, including 1 variety, were formerly recorded in the world, mainly in the Oriental region and the Palearctic region (China, Borneo, Ceylon, India, Philippines, Sarawak, Kalimantan, Afghanistan and Japan) (Distant 1916; Fennah 1949, 1950, 1956, 1965; Ishihara 1954; Dlabola 1957; Chou et al. 1985, 1994; Chen & Lin 2001).

To date, the majority of species in the genus, with the exception of *C. japonicus* Ishihara (Japan: Shikoku) and *C. cardinalis* Fennah (Philippines: Luzon), are described from specimens collected in China, namely *C. indicus* Distant (Jiangxi), *C. ulysses* Fennah (Sichuan, Yunnan), *C. fopingensis* Chou et al. (Shaanxi), *C. ziyangensis* Chou et al. (Shaanxi, Yunnan), *C. asymmetries* Chou et al. (Yunnan), *C. symmetries* Chou et al. (Yunnan), *C. nigripectus* Chou et al. (Yunnan), and *C. jilinensis* Chou et al. (Jilin) (Fennah 1956; Chou et al. 1985, 1994; Chen & Lin 2001).

During the course of studying biodiversity in Maolan National Nature Reserve in Guizhou Province, southwest China, two fulgorid specimens belonging to the unknown species of the genus *Caristianus* Distant were found. The purpose of this paper is to describe two new species and to provide an identification key to the species of *Caristianus*.

MATERIALS AND METHODS

Morphological techniques and terminology follows Fennah (1950) and Chou et al. (1994). Specimens examined are deposited in the Insect Collection at the Institute of Entomology, Guizhou University, Guiyang, Guizhou Province, China (IEGU).

DESCRIPTIVE TAXONOMY

Caristianus Distant

Caristianus Distant, 1916, 6: 63. Type species: *C. indicus* Distant, 1916, by original designation.

Caristianus Distant: Fennah, 1950, Bull. Brit. Mus. (N.H.) Ent., 1:103.

Caristianus Distant: Chou et al., 1994, Entomotaxonomia, 16(1): 38.

The distinctive characters used by Fennah (1950) and Chou et al. (1994) are modified as follows:

Head with eyes distinctly narrower than pronotum. Vertex slightly declivous, longer in

middle than broad across base (1.2-1.9:1), produced before eyes for about half of their length; median carina present, obsolete distally; disk strongly depressed; anterior margin carinate, strongly convex; lateral margins carinate, straight, diverging basad; posterior margin transverse. Frons moderately convex in profile, longer in middle line than broad (1.3-1.9:1), widest part about three times as wide as base; basal margin convex-truncate; median carina distinct, percurrent; lateral margins carinate, sinuately diverging to level of antennae then gradually incurved to suture, rather obliquely foliate; disk of frons not depressed. Clypeus more than half as long as frons, medially and laterally carinate. Rostrum with subapical segment shorter than apical. Antennae subglobose, not sunk in a depression. Ocelli touching eyes. Eyes distinctly excavate beneath, only slightly overlapping pronotum.

Pronotum moderately short, about as long behind eyes as in middle line; anterior margin of disk truncate, posterior margin angulately excavate; median carina present; lateral carinae of disk straight, diverging basad, attaining hind margin, each not quite as long as median carina; two incomplete carinae between eye and tegula; pronotum laterad of disk slightly inclined anteroventrally; ventral margin of lateral lobes slightly oblique. Mesonotum longer than vertex and pronotum together, tricarinate, lateral carinae straight, weakly divergent. Tegulae not carinate. Posttibiae with a single spine basad of middle.

Tegmina 3 times as long as broad, costal margin slightly convex; Sc+R fork near basal quarter, basad of union of claval veins; M forked level with node; Cu1 fork basad of apex of clavus and distad of union of claval veins; 7 apical areoles distad of stigma. Clavus terminating distad of middle.

KEY TO SPECIES OF *Caristianus* DISTANT

1. Pronotum and mesonotum with lateral areas outside lateral carinae blackish brown or purplish brown, central areas ivory-yellow or milky white (Fig. 1; Chou et al. 1994: Fig. 1: E; Ishihara 1954: Fig. 16: 1); costal areas of tegmina with ivory-yellow longitudinal band, enlarging from base to apex (Fig. 1; Chou et al. 1994: Fig. 1: E; Distant 1916: Fig. 48) 2

—Pronotum and mesonotum blackish or stramineous (Fig. 8); costal areas of tegmina without ivory-yellow longitudinal band, but with some milky white markings (Fig. 10; Ishihara 1954: Fig.16: 4; Fennah 1965: Fig. 68) 10

2. Frons almost blackish brown or brown (Fig. 2; Chou et al. 1994: Fig. 1: F; Distant 1916: Fig. 48) 3

—Frons blackish brown or purplish brown, except apically with yellowish white transverse band (Fig. 9; Ishihara 1954: Fig. 16: 2; Fennah 1965: Fig. 66) 7

3. Median carina of frons distinct, percurrent; clypeus without yellow transverse markings or only with 1 small yellow or milky white markings at apical-lateral angle 4

—Median carina of frons only basal ¼ distinct; clypeus with 1 grayish white transverse marking basally (Chou et al. 1994: Fig. 1: F) . . . . . *C. fopingensis*

4. Sc+R of tegmina fork near base; costal areas with ivory-yellow longitudinal band from near base to near apex, long and broad (Fig. 1) 5

—Sc+R of tegmina fork at middle; costal areas with ivory-yellow longitudinal band from near middle to near apex, short and narrow, and with 1 small ivory-yellow triangular marking before this band . . . . . *C. asymmetries*

5. The apical cells of tegmina banded with grayish white color (Distant 1916: Fig. 48) . . . . . *C. indicus*

—The apical cells of tegmina banded with red color 6

6. Clypeus with apex ivory-yellow (Fig. 2); tegmina with 1 small blackish brown marking near apex of Sc1 (Fig. 1); body smaller (length including tegmina 3.8 mm) . . . . . *C. maolanensis*

—Clypeus purplish brown (Chou et al. 1994: Fig. 6: F); tegmina without blackish brown marking near apex of Sc1 (Chou et al. 1994: Fig. 6: A); body larger (length including tegmina 6.9 mm) . . . . . *C. jilinensis*

7. The yellowish white transverse band of frons broad (more than ⅓ of frons); styles of aedeagus symmetrical 8

—The yellowish white transverse band of frons narrow (only 1/5 of frons); styles of aedeagus asymmetrical (Chou et al. 1994: Fig. 4: A, B) . . . . . *C. symmetries*

8. Frons with apical ⅓ yellowish white (Ishihara 1954: Fig. 16: 2); Sc+R of tegmina fork near basal 2/5, costal areas with 1 small triangular marking before ivory-yellow longitudinal band (Ishihara 1954: Fig. 16: 4); body dark brown . . . . . *C. japonicus*

—Frons with apical ½ yellowish white; Sc+R of tegmina fork near middle, costal areas without small triangular markings before ivory-yellow longitudinal band; body purplish brown or light purplish brown 9

9. Styles of aedeagus with 1 larger tooth near apex; aedeagus with 5 or 6 teeth on each side (Chou et al. 1994: Fig. 2: A . . . . . *C. ziyangensis*

—Styles of aedeagus and aedeagus without teeth (Fennah 1956: Fig. 15: K) . . . . . *C. ulysses*

10. Vertex longer in middle than broad at base about 1.9:1 (Fennah 1965: Fig. 65); tegmina with 4 short longitudinal fuscous-piceous stripes at apical margin (Fennah 1965: Fig. 68); body of male light yellowish brown, of female scarlet . . . . . *C. cardinalis*

—Vertex longer in middle than broad at base about 1.25-1.4:1 (Fig. 8); tegmina without short longitudinal fuscous-piceous stripes at apical margin (Fig. 10); body blackish brown 11

11. Frons purplish black; costal areas of tegmina with 3 small white markings; apex of aedeagus with 1 slender process on each side, directed laterad; styles of aedeagus as long as aedeagus, with apices crossing each other (Chou et al. 1994: Fig. 5: A) . . . . . *C. nigripectus*

—Frons with apical half milky white (Fig. 9); costal areas of tegmina with 1 large and 1 small marking, ivory-yellow (Fig. 10); aedeagus with subapically 2 processes, directed basad; styles of aedeagus shorter obviously than aedeagus, with apices diverging (Figs. 14-16) . . . . . *C. liaoi*

Caristianus maolanensis Chen et Li **sp. nov.**
(Figs. 1-7)

Description. Body length (from apex of vertex to tip of abdomen): male 2.4 mm; including tegmen: male 3.8 mm; tegmen length: male 3.1 mm. Vertex subrectangular (Fig. 1), longer in middle than broad across base (1.3:1). Frons narrow triangle, longer in middle line than broad (1.7:1), median carina with apical 4/5 distinct (Fig. 2). Rostrum long, surpassing trochanter of median leg. Mesonotum longer than vertex and pronotum together (1.6:1). Sc+R of tegmina fork near basal ⅓. Post-tarsomeres with segment I longer than II and III together (1.3:1).

Anal segment of male broad at base and narrow at apex, distal margin convex, notched at middle. Pygofer with each lateral margin produced near middle in 1 twisted digitate process, with 1 small tooth on its outer side (Figs. 3 and 4). Medioventral process deeply bifid, each limb long spine-like, diverging distally, with 1-2 small teeth on each outer side near basal ⅓ (Fig. 4). Aedeagus swelling at apex, lateral margin sinuate, with 7-8 small teeth on each side. In ventral view, aedeagus with 2 strong processes produced from apex, directed ventrocephalad. Styles of aedeagus symmetrical, as long as aedeagus, diverging at middle and closing to each other distally (Figs. 6 and 7). Genital styles moderately expanding distad, sinuate on ventral and dorsal margin, with 2 simple teeth near middle and apex of dorsal margin, one slender, sinuate process originating from ventral margin and directed dorsad (Fig. 5).

Vertex yellowish brown, except for two stripes laterally, and 1 stripe on each side of median carina distally brown. Frons blackish brown, except for apical angle milky white and 5 spots on lateral margin yellowish brown. Eyes blackish brown, ocelli yellowish brown, marginally tinted with red. Antenna blackish brown. Clypeus blackish brown, except for apex ivory-yellow. Rostrum yellow, but apex blackish brown. Pronotum and mesonotum blackish brown, except for lateral carinae and areas between them yellowish brown. Tegmina infuscate, middle of costal area with 1 milky white longitudinal band, in which 1 small brown spot near Sc; posterior margin of clavus milky white, inside of second claval vein with 5 small milky white spots; with veins in this area concolorous, except those veins of apical half of tegmina red. Wings slightly tinged light brown, with veins dark brown. Legs ivory-yellow. Abdomen blackish brown.

Etymology. This new species is named after the type locality, Maolan National Nature Reserve in Guizhou Province.

Distribution. Southwest China (Guizhou).

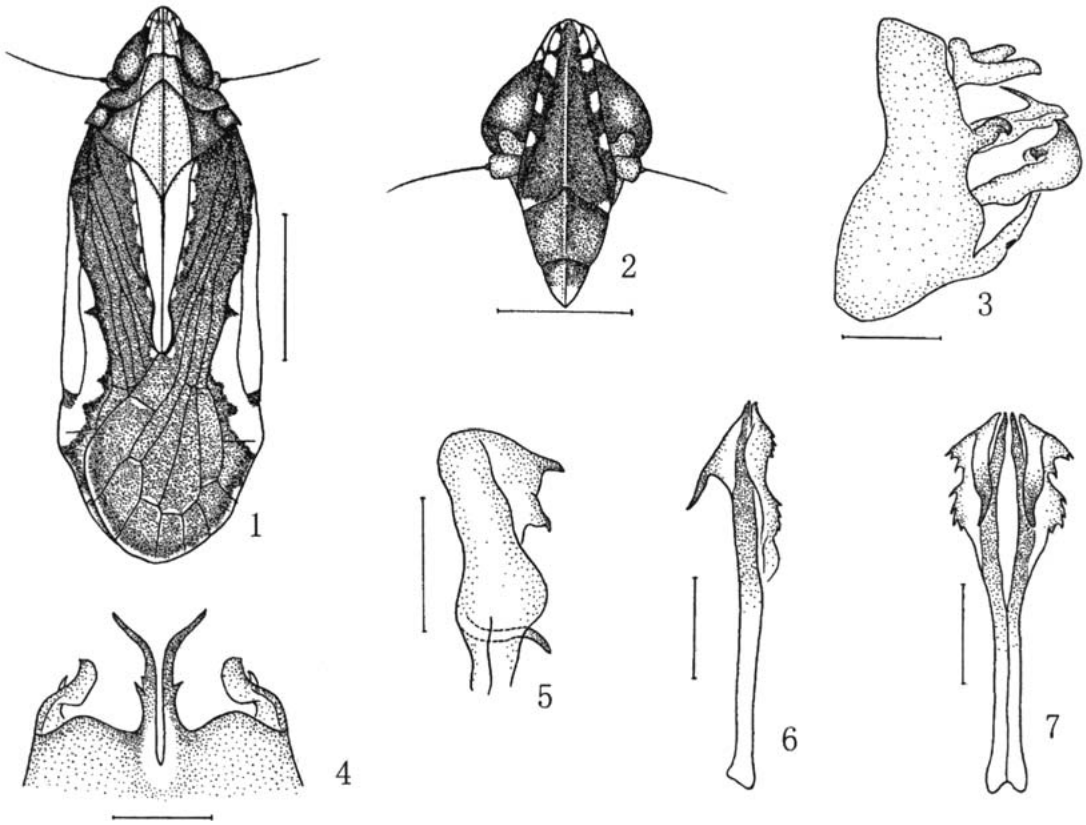
Specimens examined. Holotype male, CHINA: Guizhou, Maolan National Nature Reserve (25°40'N, 108°05'E), 600 m, 24-X-1998 (X.-S. Chen) (IEGU).

Remarks. This new species is similar to *C. asymmetries* Chou et al., but differs from the latter in: smaller body; tegmina with Sc+R fork near basal ⅓; veins of apical half red; apical half aedeagus symmetry; genital styles with slender process near base.

Caristianus liaoi Chen et Tsai **sp. nov.**
(Figs. 8-16)

Description. Body length (from apex of vertex to tip of abdomen): male 2.2 mm, female 2.8 mm; including tegmen: male 3.7 mm, female 4.7 mm; tegmen length: male 3.0 mm, female 3.9 mm.

Vertex triangular, longer in middle than broad across base (1.4:1), with median carina, posterior margin slightly sinuate (Fig. 8). Frons broad triangle, longer in middle line than broad (1.3:1),



Figs. 1-7. *Caristianus maolanensis* Chen et Li **sp. nov**. 1. male holotype, dorsal habitus; 2. frons and clypeus; 3. pygofer and anal segment, left side; 4. pygofer, ventral view; 5. right genital style, lateral view; 6. aedeagus, lateral view; 7. aedeagus, ventral view. Scale bars = 1 mm (Fig. 1); 0.5 mm (Fig. 2); 0.2 mm (Figs. 3-7).

median carina with apical ⅓ distinct (Fig. 9). Rostrum long, surpassing trochanter of median leg. Mesonotum longer than vertex and pronotum together (1.5:1). Sc+R of tegmina forking near basal 2/5. Post-tarsomeres with I segment longer than II and III together (1.2:1).

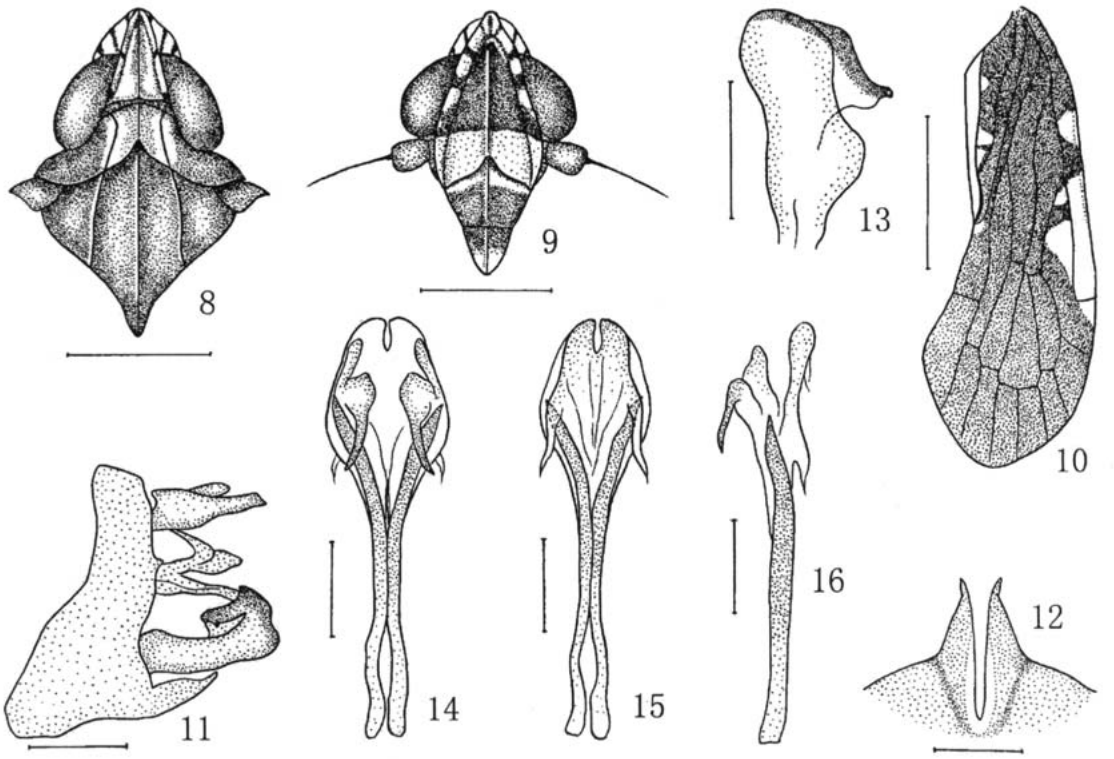
Anal segment of male broad at base and narrow at apex, distal margin concave roundly. Pygofer with each lateral margin produced near middle into tooth (Figs. 11). Medioventral process deeply bifid, each limb broad at base, acuate at apex, diverging distally (Fig. 12). Aedeagus swelling at apex, lateral margin slick, anterior margin with groove. In ventral view, aedeagus with 2 strong processes produced from subapical margin, directed ventrocephalad. Styles of aedeagus symmetrical, shorter than aedeagus, diverging distally (Figs. 14-16). Genital styles moderately expanding distad, sinuate on ventral margin, with 2 large cone-shaped teeth near apex of dorsal margin (Fig. 13).

Vertex yellowish brown, except for 2 stripes laterally, and a stripe on each side of median carina distally brown (Fig. 8). Frons with basal half blackish brown, apical half milky white and 5 spots on lateral margin yellowish brown. Eyes reddish brown, ocelli yellowish brown. Antenna blackish brown. Clypeus blackish brown, except for basal margin ivory-yellow and apex yellowish brown. Rostrum yellowish brown, but apex blackish brown. Pronotum and mesonotum blackish brown, except for lateral carinae of pronotum yellowish brown (Fig. 8). Tegmina infuscate, middle of costal area with 1 large milky yellow marking and 1 small milky yellow marking; posterior margin of clavus yellowish brown, inside of second claval vein with 3 milky white spots; with veins in this area concolorous (Fig. 10). Wings slightly tinged light brown, with veins dark brown. Legs yellowish brown. Abdomen blackish brown.

Etymology. This new species is named in honor of Ms. Q.-R. Liao, collector of the type specimens.

Distribution. Southwest China (Guizhou).

Specimens examined. Holotype male, CHINA: Guizhou, Maolan National Nature Reserve (25°40'N, 108°05'E), 600 m, 25-X-1998 (Q.-R. Liao) (IEGU). Paratype 3 females, same data as holotype.



Figs. 8-16. *Caristianus liaoi* Chen et Tsai **sp. nov**. 8. head and thorax, dorsal view; 9. frons and clypeus; 10. tegmen; 11. pygofer and anal segment, left side; 12. medioventral process of pygofer; 13. right genital style, lateral view; 14. aedeagus, ventral view; 15. aedeagus, dorsal view; 16. aedeagus, lateral view. Scale bars = 0.5 mm (Figs. 8-9); 1 mm (Fig. 10); 0.2 mm (Figs. 11-16).

Remarks. This species is similar to *C. cardinalis* Fennah, but differs from the latter in: vertex shorter (longer in middle than broad across base about 1.4×, not 1.9×); on tegmina, the base of costal cell without ivory yellow spots and the apical cells without short longitudinal fuscous-piceous stripes; pygofer with each lateral margin produced near middle in a tooth, not long process; medioventral process deeply bifid; aedeagus with two strong processes produced from subapical margin, directed ventrocephalad.

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SYNONYMY OF TWO ARBOREAL TERMITES (ISOPTERA: TERMITIDAE: NASUTITERMITINAE): *NASUTITERMES CORNIGER* FROM THE NEOTROPICS AND *N. POLYGYNUS* FROM NEW GUINEA

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ABSTRACT

Morphological examination of soldiers and imagos assigned to *Nasutitermes polygynus* from New Guinea were determined to be conspecific with the neotropical species, *N. corniger*. A portion of the mtDNA 16S rRNA gene was sequenced from nine *N. corniger* samples and found to be congruent with that reported for *N. polygynus*. Complementary biological, behavioral, chemical, and reproductive ecology data further support this synonymy. *Nasutitermes corniger* was likely introduced to New Guinea as a result of accidental human transport.

Key Words: arboreal termites, taxonomy, distribution

RESUMEN

Se determinó por medio de una examinación morfológica de los soldados e imagos de *Nasutitermes polygynus* de Nueva Guinea que esta especie es conespecifica con la especie Neotropical, *N. corniger*. Se determinó que una porción de ADNmt 16S ARNr que fue secuenciada de nueve muestras de *N. corniger* fue congruente con la porción de ADN conocida para *N. polygynus*. Los datos biologicos complementarios, el comportamiento, además de la ecologia química y reproductiva apoyan esta sinonomia. Es probable que, *Nasutitermes corniger* fue introducida al Nueva Guinea como resultado accidental del transporte humano.

Nasutitermes corniger (Motschulsky 1855) has the broadest distribution of any neotropical termite species and is capable of establishment in non-endemic localities (Scheffrahn et al. 2002). In many places where *N. corniger* occurs, it is a dominant species. *Nasutitermes polygynus* Roisin and Pasteels 1985, is broadly distributed on the island of New Guinea but is less common than other arboreal nasutes from there (Roisin & Pasteels 1996).

In a molecular genetic analysis of *Nasutitermes* from the tropical Pacific, Miura et al. (2000) determined that *N. polygynus* and *N. corniger* are sister species based on single mtDNA COII and 16S rRNA sequences from each species. Miura et al. (2000) did not make morphological comparisons but noted remarkable similarities between the two species. Because of the widespread range of *N. polygynus* in New Guinea, Miura et al. (2000) hypothesized that *N. polygynus* evolved from an ancestral arrival of *N. corniger* from the New World. It was difficult, however, for the authors to reconcile a natural trans-Pacific crossing, thus inferring introduction by humans and a synonymy of *N. polygynus* and *N. corniger*.

In this paper we provide morphological, genetic, behavioral, and chemical evidence that *N. polygynus* is a synonym of *N. corniger*.

MATERIALS AND METHODS

Morphological examinations are based on an extensive collection of *N. corniger* from the New World (Scheffrahn et al. 2005) and nine samples from New Guinea. A synopsis of synonymy of *N. corniger* is presented in Scheffrahn et al. (2005) with the following additions:

Nasutitermes corniger (Motschulsky)

Nasutitermes polygynus Roisin and Pasteels 1985: [imago, Fig. 1; soldier Fig. 2. Type loc.: Papua New Guinea, Nubia, 3 km on road to Bunapas (Bogia District)]; Roisin & Pasteels 1996: 546-551 [imago, Fig. 40; soldier Fig. 41; large worker, Figs. 42, 43; distribution, Fig. 44]; Roisin & Pasteels 1986: 149-167 [polycaly, polygyny] Roisin & Pasteels (1985) described *N. polygynus* from specimens collected in northeastern Papua New Guinea. Additional soldiers from

southeastern and southwestern Papua New Guinea were measured in their redescription (Roisin & Pasteels 1996) that also included photographs of the soldier, large worker mandible, and large worker enteric valve armature.

Material Examined

All specimens are from Island of New Guinea and were fixed in Bouin or FAA. TYPE COLONY of *N. polygynus*, Nubia, Hansa Bay, Bogia District, 3 km on road to Bunapas, 16-XI-1978; J. M. Pasteels (PNGT 4). Nubia, Hansa Bay, Bogia District, Sakula River bridge; Y. Roisin; 2-I-1984 (PNGT 508). Bunapas, Ramu River, Bogia District, behind airstrip; Y. Roisin; 23-VII-1984 (PNGT 751). Sisimangum, Hansa Bay, Bogia District; Y. Roisin; 8-IX-1984 (PNGT 827). Bogia, 12 km on road to Josephstaal, Bogia District; Y. Roisin and J. M. Pasteels; 25-II-1985 (PNGT 900). Gogol River valley, S. of Madang, 35 km from main (coastal) road; Y. Roisin; 16-IX-1988 (PNGT 1274). Lake Murray, Western Province; Y. Roisin and M. Leponce; 23-V-1990 (PNGT 1566). Nabire (Irian Jaya); Y. Roisin; 12-XI-1995 (IRJT 3). Kaimana (Irian Jaya), near airstrip; Y. Roisin; 21-XI-1995 (IRJT 118).

Genetic Analysis

DNA was extracted from four *Nasutitermes ephratae* (Holmgren), one *N. guayanae* (Holmgren), one *N. nigriceps* (Haldeman), one *N. rippertii* (Rambur), and nine *N. corniger* samples from the Dominican Republic, Dominica, Nevis, Guadeloupe, Puerto Rico, Mexico, Ecuador, Suriname, and Jamaica per Szalanski et al. (2004). Polymerase chain reaction (PCR) was conducted with the primers LR-J-13007 (5'-TTACGCTGTTATCCCTAA-3') (Kambhampati & Smith 1995) and LR-N-13398 (5'-CGCCTGTTTATCAAAAACAT-3') (Simon et al., 1994). These PCR primers amplify an approximately 428-bp region of the mtDNA 16S rRNA gene. PCR reactions were conducted with 1 µl of the extracted DNA per Szalanski et al. (2000), with a profile consisting of 35 cycles of 94°C for 45 s, 46°C for 45 s and 72°C for 45 s. Amplified DNA from individual termites was purified and concentrated on Microcon-PCR Filter Units (Millipore, Bedford, MA). Samples were sent to University of Arkansas Medical Sciences DNA Sequencing Core Facility (Little Rock, AR) for direct sequencing in both directions with an ABI Prism 377 DNA sequencer (Foster City, CA). GenBank accession numbers for the *Nasutitermes* termites subjected to DNA sequencing in this study are AY623085 to AY623100. Consensus sequences for each sample were obtained by using BioEdit 5.09 (Hall 1999). The position of variable nucleotide sites among the DNA sequences was obtained with MacClade v4 (Sinauer Associates, Sunderland, MA).

The distance matrix option of PAUP* 4.0b10 (Swofford 2001) was used to calculate genetic distances according to the Kimura 2-parameter model (Kimura 1980) of sequence evolution. Mitochondrial DNA sequence of *N. acajutlae* (Holmgren) (Kambhampati et al. 1996) was included for phylogenetic analysis, along with mtDNA 16S sequences for *N. polygynus*, *N. triodiae* (Froggatt), *N. magnus* (Froggatt), *N. walkeri* (Hill), *N. exitiosus* (Hill), *N. princeps* (Desneux), *N. bikpelanus* Roisin and Pasteels and *N. pinocchio* Roisin and Pasteels from Miura et al. (2000). *Longipeditermes longipes* (Haviland) and *Hospitalitermes medioflavus* (Holmgren) (Termitidae: Nasutitermitinae) sequences from Miura et al. (2000) were used as the outgroup taxa for the *Nasutitermes* dataset. DNA sequences were aligned with CLUSTAL W (Thompson et al. 1994) and adjusted manually. Maximum likelihood and unweighted parsimony analysis on the alignments were conducted by using PAUP* 4.0b10 (Swofford 2001). Gaps were treated as a fifth character state. The reliability of trees was tested with a bootstrap test (Felsenstein 1985). Parsimony bootstrap analysis included 1,000 resamplings with the Branch and Bound algorithm of PAUP*. For maximum likelihood analysis, the default likelihood parameter settings were used (HKY85 6-parameter model of nucleotide substitution, empirical base frequencies) with the exception of the transition/transversion ratio, which was set to 1.357845:1. These parameters were used to carry out a bootstrap analysis by either step-wise addition or the maximum parsimony tree as the starting tree.

Results

Geographical Distribution

Nasutitermes corniger occurs over a north-south distance of more than 6,000 km from southern Mexico to northern Argentina, including the West Indies, and much of the region except Chile, Uruguay, and the Bahamas (Scheffrahn et al. 2005). There is one introduced population in southeastern Florida (Scheffrahn et al. 2002) currently under an eradication program. The distribution of *N. polygynus* is given in Figure 1.

Morphology

Roisin & Pasteels (1985, 1996) reported some variability in measurements as observed by Scheffrahn et al. (2005), but character dimensions of *N. corniger* (Scheffrahn et al. 2005) from the Neotropics and *N. polygynus* from New Guinea (Roisin & Pasteels 1996) overlap for all 12 comparable measurements (7 imagos, 5 soldiers). Coloration, pilosity, and fine structure for both groups are also congruent (Fig. 2).

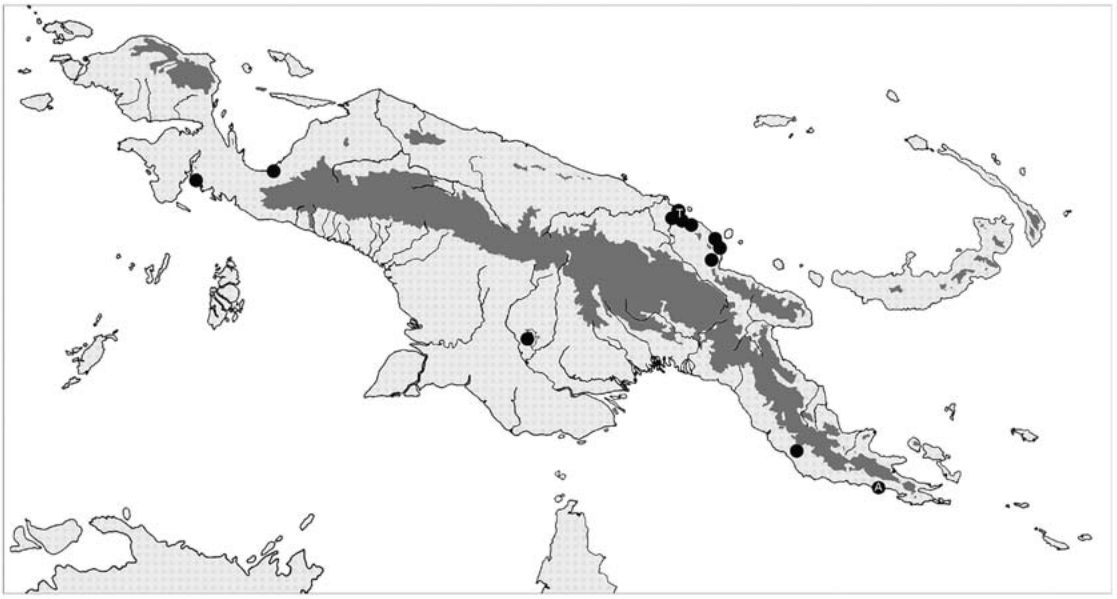

Fig. 1. Collection sites (dark circles) of *Nasutitermes corniger* in New Guinea. Dark grey: elevation above 1000 m.

Genetic Analysis

The 428-bp region of the mtDNA 16S rRNA gene was subjected to DNA sequencing from *Nasutitermes corniger* and 13 other *Nasutitermes* taxa (Fig. 3). Among the nine *N. corniger* DNA sequences, 13 nucleotides were variable and genetic diversity ranged from 0.0% between the Guadeloupe and Nevis samples to 1.8% between the Jamaica and Nevis samples. To facilitate analysis with the DNA sequences from Miura et al. (2000) 17 base pairs at the 5' end of our DNA sequences were excluded for phylogenetic analysis. The aligned DNA data matrix, which included 14 *Nasutitermes* taxa as well as the two outgroup taxa, resulted in a total of 421 characters. Of these characters, 111 (26%) were variable and 63 (15%) were phylogenetically informative. This dataset had only one most parsimonious tree (Fig. 4), (length = 272, CI = 0.577), as documented using the Branch and Bound search algorithm of PAUP*. Bootstrap analysis of the aligned *Nasutitermes* taxa revealed that *N. corniger* and *N. ephratae* are monophyletic. Based on genetic distance data, the *N. polygynus* DNA sequence from Miura et al. (2000) collected from New Guinea was most similar to *N. corniger* from Mexico and Ecuador. The consensus tree from the maximum likelihood analysis (-ln L = 1672.20365) was identical to the maximum parsimony analysis.

Discussion

The synonymy of *N. polygynus* and *N. corniger* is supported by morphological and genetic congruency. Furthermore, Roisin & Pasteels (1986) reported biological similarities for *N. corniger* and *N. polygynus* by virtue that both species are polygynic and build polycalic (satellite) nests. Also like *N. corniger*, Roisin & Pasteels (1996) report crepuscular dispersal flights for *N. polygynus* following the first rains of the wet season.

Vrkoc et al. (1973) identified six monoterpenes in the defensive secretion of *N. costalis* (=*corniger*) from Cuba including the two major components, terpinolene and limonene, found in *N. polygynus* (Everaerts et al. 1988). The major diterpenic components identified from the defensive secretion of *N. polygynus* are trinervita-1(15),8(19)-dien-2β,3α-diol and trinervita-1(15),8(19)-dien-2β-ol (Dupont et al. 1981: *Nasutitermes* sp. B). Vrkoc et at. (1978) identified the diol as the major diterpene component in the defensive secretion of *N. corniger* from Cuba. In the four populations of *N. corniger* from Central America analyzed by Gush et al. (1985), the diol is also dominant, although sometimes partially replaced by its 2α,3α and 2α,3β-diol isomers, whereas the latter constitutes 0.4-21.4% of the diterpenic fraction.

We hypothesize that *N. corniger* was introduced to New Guinea as a result of unintentional human transport. This species was actually intercepted several times in the U.S. and the U.K. in plants from Central America or the West Indies (Gay 1967). Established populations have been introduced to Florida and Scotland (Scheffrahn et al. 2002) and recent interceptions from Columbia and Puerto Rico have been recorded, respectively, in Clearwater and Jacksonville, Florida. We, like

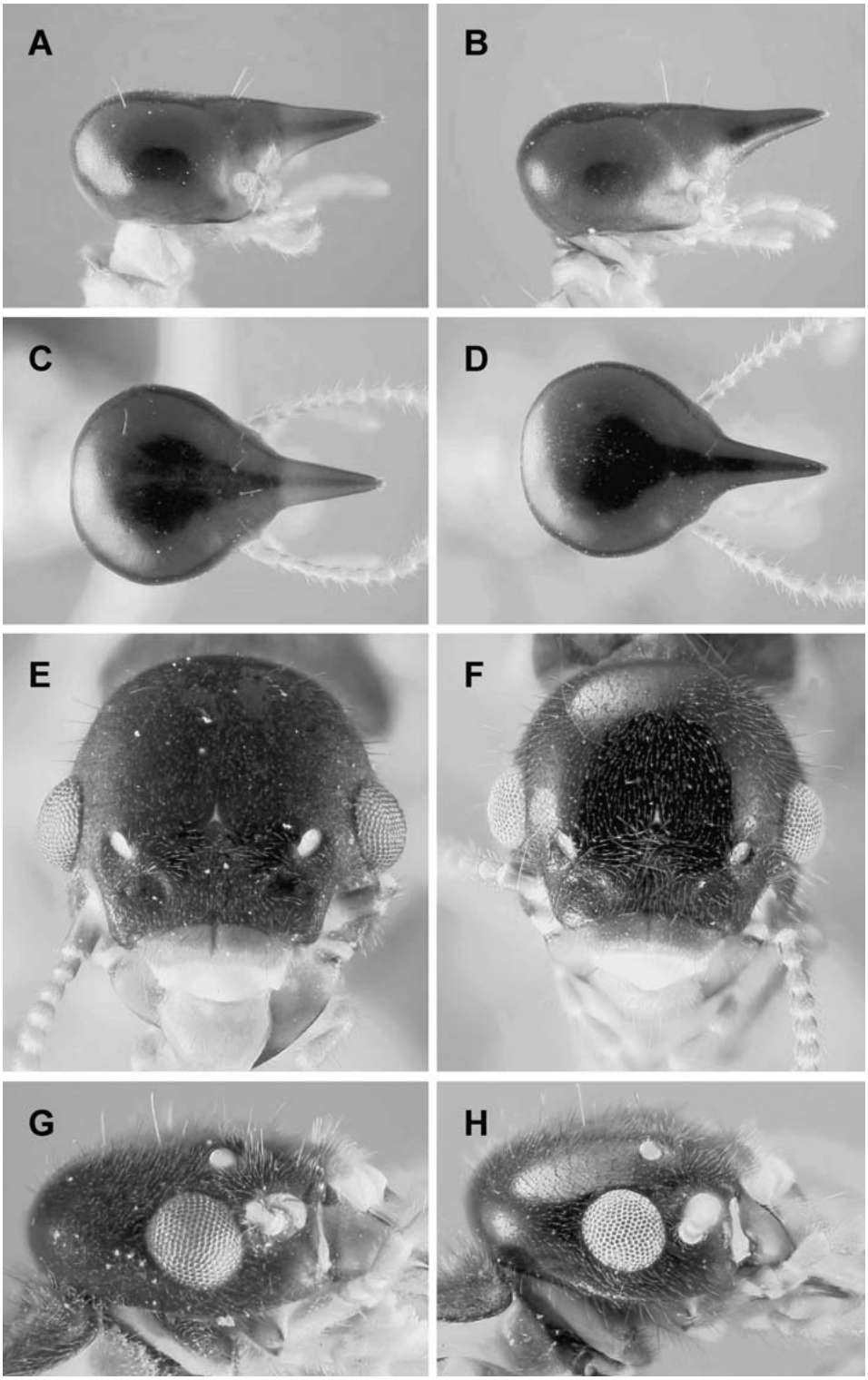

Fig. 2. Photomicrographs of *Nasutitermes corniger*. Lateral (A) and dorsal (C) views of soldier head capsule from Irian Jaya, New Guinea. Lateral (B) and dorsal (D) views of soldier head capsule from Honduras. Dorsal (E) and lateral (G) views of imago head capsule from Irian Jaya, New Guinea. Dorsal (F) and lateral (H) views of imago head capsule from Venezuela.

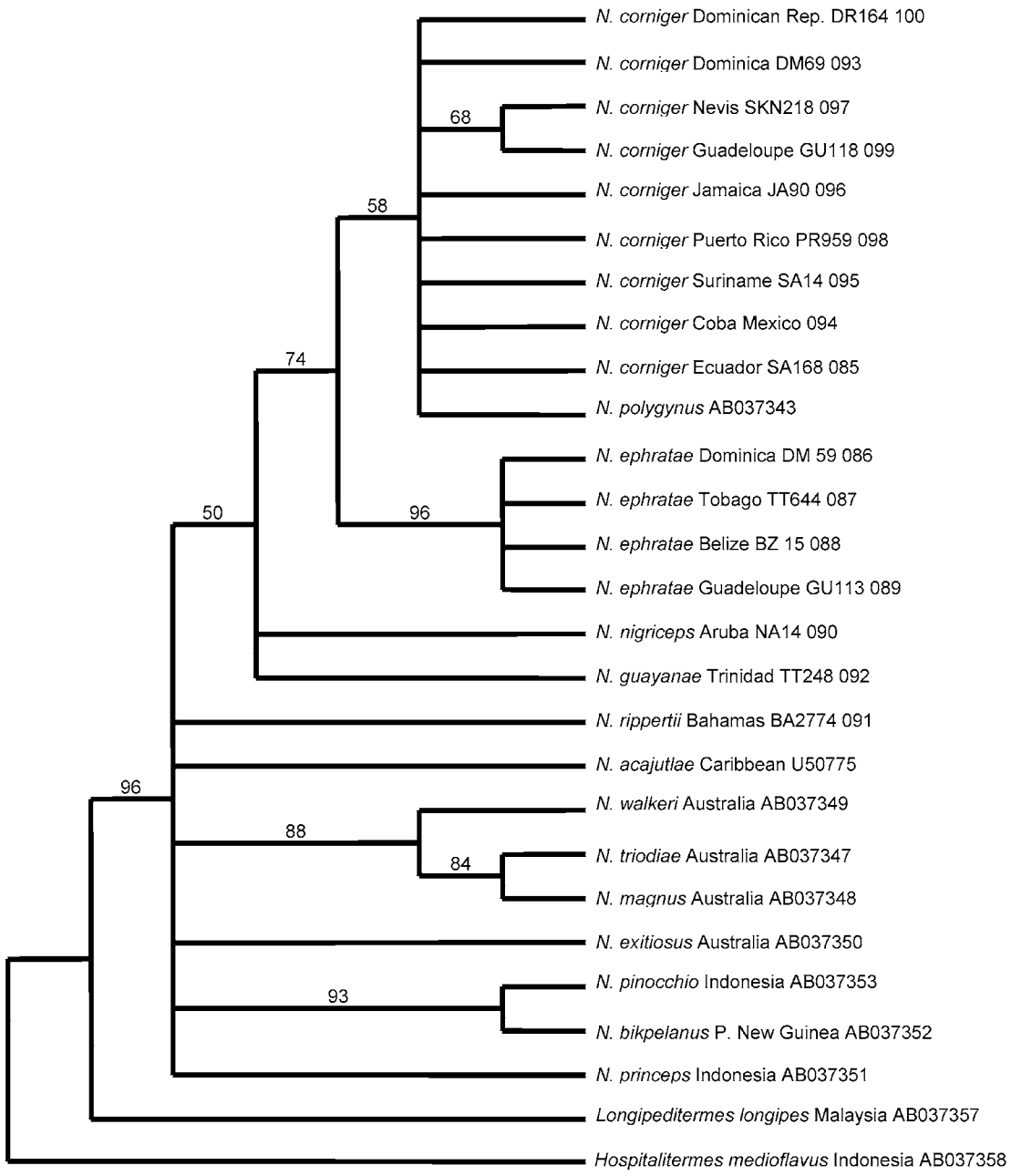

Fig. 3. Single most parsimonious tree during a branch and bound search from PAUP* (Swofford 2001). Bootstrap values for 1,000 replicates are listed above the branches supported at ≥50%. GenBank accession numbers for samples not sequenced in this study also are provided.

Miura et al. (2000), find it difficult to explain the widely separated localities (≤1900 km, Fig. 2) of *N. corniger* on the island of New Guinea. We speculate that the New Guinea distribution is the result of (1) a single early maritime introduction centuries ago from which the termites dispersed around New Guinea, possibly helped by human transportation, (2) multiple recent introductions by ship or aircraft, or (3) a combination of both. The fact that *N. corniger* has not been reported from other islands in the southwestern Pacific region suggests that introductions into this region have been few, making the first hypothesis more likely.

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TWO NEW SPECIES OF THE GENUS *CAMPTOLOMA* (LEPIDOPTERA: NOCTUIDAE) FROM CHINA

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ABSTRACT

Two colorful medium-sized moths, *Camptoloma kishidai* **sp. nov.** and *C. bella* **sp. nov.**, from South China, are described and illustrated. *C. kishidai* can be recognized from the related species *C. carum* Kishida, from Taiwan by the reddish yellow-ground color on the forewing upperside, the tornal area without an irregular red pink patch, and by antemedian and postmedian fasciae connected at their lower ends by a longitudinal fascia. *C. bella* is distinguished from the allied species *C. interiorata* (Walker) by the characteristics of a reddish patch, and discocellular, antemedian and postmedian fasciae. A key to the species of the genus is supplied. All the type specimens are deposited in the Laboratory of Insect Ecology, South China Agricultural University.

Key Words: Taxonomy, Noctuidae, Shimentai Nature Reserve, Cengwanglaoshan Nature Reserve

RESUMEN

Dos mariposas nocturnas de colorido aspecto y mediano tamaño *Camptoloma kishidai* **sp. nov.** y *C. bella* **sp. nov.** del sur de China son descritas e ilustradas. Se puede reconocer *C. kishidai* de *C. carum* Kishida, una especie cercana de Taiwan por el color amarillo-rojiso de la parte superior del ala anterior, el área tornal no presenta la mancha irregular de color rojo-rosado, y por las fasciae antemedianos y posteromedianos que se conectan al los terminos basales por una fascia longitudinal. Se distingue *C. bella* de *C. interiorata* (Walker), una especie aliada, por las caracteristicas de la mancha roja, y por el discocelular y las fasciae antemediana y posteromediana. Se provee una clave de las especies del género *Camptoloma*. Todos los especimenes tipo estan depositados en el Laboratorio de Ecologia de Insectos, de la Universidad Agrícola del Sur de China.

As a part of biodiversity conservation for sustainable development, an inventory of biodiversity is important, particularly in the areas of tropical and subtropical regions that housed such numbers of species. In comparison with higher plants and larger animals, the inventory of insects is still fragmentary and incomplete. South China, within the Indo-Australian Region, is one of the major sites of biodiversity in China. In order to appeal public awareness and to develop conservation measures in this region, we started the inventory work on macrolepidoptera, including butterflies and larger moths, at selected sites.

Recently, we conducted a macrolepidoptera survey in Shimentai Nature Reserve, Guangdong Province and Cenwanglaoshan Nature Reserve, Guangxi Province. We found two species of the genus *Camptoloma* new to science. Here we give the descriptions, along with a key to the genus.

The genus *Camptoloma* consists of medium sized, colorful moths and was established by Felder (1874), with *Camptoloma erythropygum* its type species. It is closely related to the genus *Leucopardus* Hampson (1894) and forms a natural group with the latter (Kishida, 1984). Recently, the genus *Leucopardus* Hampson has been considered a synonym of the genus *Camptoloma* Felder by Holloway (1988), who moved the genus to the family Noctuidae from the family Arctiidae based on anatomical characters. In this paper, we regard *Camptoloma* and *Leucopardus* to be separated genera in agreement with some other authors (Kishida 1984; Zolotuhin 2000) due to the differences in the wing pattern, although male genitalia of the two genera are closely related in structure.

Currently, five species of the genus *Camptoloma* have been documented: *C. interiorata* (Walker [1865]) from China, Japan, Korea and the Russian Far East; *C. binotatum* Butler, 1881, from N. India and Assam, Nepal, Myanmar, and S. China; *C. carum* Kishida, 1984, from Taiwan; *C. vanata* Fang, 1994, from Jiangxi and Hainan of China, N. Vietnam, and *C. mangpua* Zolotuhin & Witt, 2000, from Sikkim.

MATERIALS AND METHODS

Specimens were collected by light traps during the field surveys conducted in Cenwanglaoshan and Shimentai Nature Reserves. The type specimens are deposited in South China Agricultural University (SCAU).

Photographs of specimens were taken with a Nikon Coolpix995, along with a Leica MZ125 for

genitalia figures. Digital images were imported into Adobe Photoshop 5.0 for labeling and plate composition.

Camptoloma kishidai **sp. nov.** (Fig. 1)

Female

Wing expanse 37 mm, length of forewing 18 mm, antenna length 9 mm. Head comparatively small; frons covered with yellow scales, subequal to the breadth of eyes; labial palpi uniformly orange yellow, rather short, coated with long scales and sparse bristles ventrally; eyes dark brown, naked; antenna filiform, dark gray except for a darker part at distal ⅓. Thorax yellow, with dorsal median and lateral brown streaks, the former one rather slimmer; legs yellow except for dorsal femura, inner tibiae and tarsi dark brown. Abdomen orange-yellow with crimson end.

Forewing nearly triangular, costa with basal ⅓ prominently arched, termen and dorsum with mid-part curved outwardly, apex pointed and tornus nearly rounded; hindwing almost rounded, costa straight. Forewing ground color reddish-orange with dark brown fasciae and spots, which is consisting of antemedian, discocellar, postmedian, submarginal and a longitudinal fascia placed on the lower basal wing, and two dark brown spots on the lower termen near tornus.

Antemedian, postmedian and discocellular fasciae distinct and well defined, the former two straight, nearly parallel to each other, and with their lower ends connected by a longitudinal dark fascia; discocellular fascia short, curved inwardly, placed nearer to antemedian fascia than to postmedian fascia; submarginal fascia obsolete, traceable; longitudinal fascia on the lower basal wing straight and with its distal end nearly arriving the lower part of antemedian fascia; marginal fascia and tornal reddish patch that represented in other *Camptoloma* species completely untraceable; cilia orange red. Hindwing ground color light orange-red, without marking, cilia orange. Underside of both wings uniformly orange-yellow.

Male. Unknown.

Holotype: Female, Shimentai Nature Reserve, 400m altitude, 24°28'N, 113°23'E, Yingde County, Guangdong Province, China, 18-IV-2003, leg. Guo-Hua Huang.

Paratype 1 female, same data as holotype.

Etymology: The name of the species is named after Mr. Y. Kishida of Tokyo, who supplied us with valuable references and suggestions.

Distribution: China (Guangdong Province).

Biology: The specimens were captured at night by light trapping, although there is a record of species in the related genus *Leucopardus* Hampson being taken flying by day (Holloway, 1988).

The new species is readily recognized from other members in the genus *Camptoloma* by the reddish-yellow forewing ground color, tornal area concolorous with the ground color, without reddish patch represented in some other related species, antemedian and postmedian fasciae connected at their lower ends by a longitudinal fascia.

Fig. 1. *Camptoloma kishidai* **sp. nov.**: Female, holotype, upperside.

Camptoloma bella **sp. nov.** (Figs. 2-4)

Male

Wing expanse 45 mm, length of forewing 23 mm, antenna length 7.5 mm. Head comparatively small; frons covered with yellow scales, with upper portion a little gray, slightly broader than the breadth of eyes; labial palpi yellow, rather short, coated with long scales and sparse bristles ventrally; legs yellow, apart from tibiae and tarsi black outwardly; eyes dark brown, naked; antenna filiform, black with white intersegmental rings. Thorax yellow with dorsal median and lateral brown streaks. Abdomen orange yellow.

Forewing triangular, somewhat longer, costa slightly arched, termen nearly straight, dorsum slightly curved, apex pointed, tornus near rounded. Hindwing nearly rounded, costa straight. Forewing ground color yellow, with typical *Camptoloma* wing pattern. Antemedian, postmedian, disocellular, submarginal and marginal fasciae dark brown and well defined, the former two fasciae slant from costa to tornal red patch, gradually narrowed to their lower ends. Discocellular fascia fine, placed nearer to postmedian fascia than to antemeddian fascia, with its lower part gradually shaded to the end of postmedian fascia. Submarginal fascia slightly curved inwardly, marginal fascia straight. The two longitudinal fasciae placed on the lower basal wing straight, well defined and nearly extending to the reddish patch; the two dark brown spots on lower termen much larger and well developed; the reddish patch in tornal area much smaller. Hindwing ground color yellow, without distinct marking. Cilia yellowish-white.

Figs. 2-3. *Camptoloma bella* **sp. nov.**; 2. Male, holotype, upperside; 3, Female, Paratype, upperside.

Male genitalia. Tegumen broad, uncus slim with pointed end, saccus short, rod-like, valva long, strongly constricted medially, costa narrow with a kidney-like costal lobe; cucullus densely coated with fragile spines; juxta with long lateral extension; aedeagus with well developed cornuti.

Female. Wing expanse 45 mm, length of forewing 23.5 mm, antenna length 8.5 mm. Similar to male in wing pattern, but wings are slightly broader, abdomen with distal end concolorous.

Holotype: Male, Cengwanglaoshan Nature Reserve, 1200 m altitude, 24°35'N, 106°40'E, Tianlin County, Guangxi Province, China, 28-V-2002, leg. Min Wang.

Paratype: 1 Female, same data as holotype.

Etymology: The name of the species, *bella*, is come from its colorful wing pattern.

Distribution: China (Guangxi Province).

The new species is related to *C. binotata* Butler in appearance, but the characteristics of reddish patch, discocellular, antemedian and postmedian fasciae make it unmistakable.

Fig. 4. Male genitalia of *Camptoloma bella* **sp. nov.**

Discussion

Members in the genus *Camptoloma* have a similar forewing pattern, the typical pattern incl. yellowish ground color with dark brown fasciae, including five transverse fasciae (e.g., antemedian, discocellular, postmedian, submarginal and marginal fasciae), and two longitudinal brown fasciae on the lower basal wings; a reddish patch at tornal region; black spots in cilia located at lower part of the termen; hindwing ground color uniform, without any marking.

The development or absence of the above mentioned characters supply useful diagnoses for different species. The most distinguished species in the genus is *C. kishidai*, which has the reddish ground color, with complete reduction of the reddish patch at tornal region that is commonly represented in other species. The second readily identified species is *C. vanata* among the remaining species with yellowish ground color, by its complete absence of most dark brown fasciae including antemedian, postmedian, submarginal and marginal fasciae. The third one is *C. carum* from Tawain with its submarginal fascia obsolete and marginal fascia absent.

The next four, *C. interiorata*, *C. binotata*, *C. mangpua*, and *C. bella* had typical *Camptoloma* wing patterns with all the fasciae and reddish patch presented. The easily recognized one is *C. mangpua* for its ill-developed tornal angle and curved antemedian fascia. *C. interiorata* is separated from the remaining ones by its finer and nearly paralleled antemedian and postmedian fasciae. *C. binotata* and *C. bella* are similar in appearance, but the discocellar fascia in *C. bella* is placed more outwardly than that in *C. binotata*.

Moreover, the reddish patch is less developed and the submarginal fascia is much broader in *C. bella*.

Though the economic importance of the two new species is uncertain, there is one species of the genus, *Camptoloma interiorata* Walker in NE. China, reported as an important insect pest on *Quercus* ssp., *Sapium sebiferum* et al. (Fang, 2000; Zheng 2001).

For the convenience of field identification, we present a key to the known species of the genus *Camptoloma* as follows:

Key to Species of the Genus *Camptoloma* Felder, 1874

1. Forewing ground color reddish-yellow ..... *C. kishidai* **sp. nov.**

   Forewing ground color yellow 2

2. Forewing upperside with submarginal fascia absent 3

   Forewing upperside with submarginal fascia present 4

3. Forewing upperside with antemedian and postmedian fasciae present ..... *C. carum*

   Forewing upperside without antemedian and postmedian fasciae ..... *C. vanata*

4. Forewing narrow without distinct anal angle, antemedian fascia with middle part curved outwardly ..... *C. mangpua*

   Forewing broader with distinct anal angle, antemedian fascia straight, or not curved outwardly 5

5. Forewing upperside with discocellular bar much nearer to postmedian fascia that to antemedian fascia ..... *C. bella* **sp. nov.**

   Forewing upperside with discocellular bar not as above stated 6

6. Forewing upperside with postmedian fascia much broader than submarginal fascia ..... *C. binotatum*

   Forewing upperside with postmedian and submarginal fascia similar in breadth ..... *C. interiorata*

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BODY WEIGHTS AND EGG LOADS IN FIELD-COLLECTED *PODISUS MACULIVENTRIS* (HETEROPTERA: PENTATOMIDAE)

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ABSTRACT

Body weights and egg loads of field populations of the spined soldier bug, *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae) were studied from grape vineyards in Florida from April to November, 2003. Two main generation peaks were found in June and September. Mean female body weight throughout the year was similar to those obtained in various crops in Indiana. In both studies, body weights were comparable to those found in laboratory experiments where females were fed 1 prey item every 3 to 9 days. Egg loads in Florida were similar to those found in field populations in Indiana. The increase in numbers of immature eggs later in the Florida season may be an indication of continued egg production in older females. We interpret this as possible evidence of synovigeny in the field. This result is consistent with previous laboratory data showing that immature eggs are continuously produced throughout female lifetime. Larger females predictably had higher mean egg loads. The similarity in biological characteristics found in field populations in Indiana and Florida suggest that the predator has similar impacts on pest species by low feeding rates.

Key Words: ovigeny, predator, grape, vineyard, pheromone

RESUMEN

El peso del cuerpo y la carga de los huevos de poblaciones del chinche, *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae), fueron estudiados en viñas en la Florida desde abril hasta noviembre de 2003. Se encontró dos picos en las generaciones principales en junio y septiembre. El promedio del peso del cuerpo de las hembras atravéz del año fue similar al obtenido de hembras en varios cultivos en Indiana. En ambos estudios, el peso del cuerpo fue comparable al obtenido de los experimentos de laboratorio donde las hembras fueron alimentadas con 1 unidad de presa cada 3 a 9 dias. La carga de huevos en la Florida fue similar a las encontradas en poblaciones de campo en Indiana. El aumento en el número de huevos inmaduros mas tarde durante la estación en Florida puede ser una indicación de la producción continua por parte de hembras mas viejas. Nosotros interpretamos este como evidencia posible de sinovogenia (la producción de huevos atravéz de la vida de la hembra) en el campo. Este resultado es consistente con los datos del laboratorio previos demostrando que los huevos inmaduros continuamente producidos durante la vida de la hembra. Como esperamos, las hembras mas grandes tenian un promedio mayor de carga de huevos. La similitud en las características biológicas encontradas en las poblaciones en el campo en Indiana y Florida sugiere que el depredador tiene un impacto similar sobre las especies de plagas por las tasas bajas en alimentación.

The spined soldier bug, *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae), is found throughout North America and known to feed on >75 species of insect prey, primarily immature Coleoptera and Lepidoptera (McPherson 1980). Because the predator also plays a role in natural control of key pests and is available as a commercial control agent, much is known about its biology under laboratory conditions (e.g., Drummond et al. 1984; Legaspi & O'Neil 1993a, b, 1994; Wiedenmann & O'Neil 1991). In contrast, relatively few studies have investigated *P. maculiventris* in the field (see Evans 1982; O'Neil 1988; Wiedenmann & O'Neil 1992).

In field-cage experiments, the estimated attack rate of *P. maculiventris* on the Mexican bean beetle, *Epilachna varivestis* Mulsant (Coleoptera: Coccinellidae) was ≈0.5 per day at low (sub-economic) prey densities of <10 prey/m^2 crop leaf area (Wiedenmann & O'Neil 1992; O'Neil 1997). At higher densities of ≈10-42 prey/m^2, representing economic pest levels, maximal attack rates were ≈2 per day. In spite of such low attack rates, *P. maculiventris* is able to persist in a variety of cropping systems through several adaptive mechanisms. Under conditions of food scarcity, *P. maculiventris* maintains longevity, but reduces its fecundity (Legaspi & O'Neil 1993a; Legaspi & Legaspi 1998). Starvation causes an increase in levels of lipid, which the predator uses as energy reserves (Legaspi & O'Neil 1994). Body mass also declines (O'Neil & Wiedenmann 1990; Legaspi & O'Neil 1993b). Furthermore, the predator may enhance its survival through phytophagy to provide water and possibly carbohydrates (Wiedenmann et al. 1996).

Legaspi et al. (1996) compared body weights, egg loads and lipid levels in female *P. maculiventris* collected in alfalfa, potato, soybeans, and fallow fields in Indiana from 1987 to 1989 against laboratory individuals under controlled feeding regimens. Field populations showed levels of these parameters comparable to laboratory specimens provided 1 prey item every 3-9 d, thus supporting the earlier finding of low field predation rates (Wiedenmann & O'Neil 1992). Furthermore, body lipid levels were higher during the drought year of 1988, suggesting conservation of energy reserves, as documented in the laboratory (Legaspi & Legaspi 1998). In this study, we compared body weights and egg loads in *P. maculiventris* collected by pheromone traps in Florida muscadine grape vineyards in 2003 against laboratory females under known feeding regimens.

Materials and Methods

From April 17 to November 14, 2003, *P. maculiventris* were collected from the FAMU-Center for Viticulture muscadine grape vineyard about 10 miles east of campus in Tallahassee, Florida (Leon County). Sampling methods were similar to those described in Legaspi et al. (2004). A glass vial filled with pheromone mixture (Aldrich 1988) and a cotton wick, as well as a vial of water inserted with a cotton wick, were placed inside each plastic covered trap. The trap was made from an inverted plastic food container. Insects entered through a wire screen funnel at the top and were removed through the screw cap lid at the bottom. The pheromone mixture and water were replaced bi-weekly or as needed. From April 17 to June 23, 11 traps were used (14 cm diameter × 24 cm height). The number of traps used was increased to 16 from June 24 to July 9 (14 cm diameter × 19 cm height), and to 27 from July 10 to November 14, 2004 (15 cm diameter × 21 cm height). Field collections were made mainly around 3:00 p.m., when most adults were observed to be caught. Samples were collected daily except the weekends. Some *P. maculiventris* adults were observed to feed on prey such as glassy-winged sharpshooter, flies, and spiders. Adult *P. maculiventris* collected from the traps were weighed individually in the laboratory on a Mettler PB 3002 analytical balance (Mettler Toledo, Hightstown, NJ) with a precision of ±0.0001 g.

All adults were kept in an ultra-low freezer at -80°C (Revco Model ULT 1786-3-A36, Kendro Laboratory Products, Asheville, NC) until dissections of female adults were done to measure the numbers of eggs in the ovaries. Methods of dissection and egg load measurements follow methods described in Legaspi et al. (2004). The dorsal and ventral abdominal body walls of the females were separated and the numbers of eggs in the ovaries were counted. Eggs were classified as mature (bigger, dark-colored, rough texture, and chorion prominent) and immature (light-colored, smooth texture, chorion not prominent).

Statistical Analysis

Linear regressions on egg loads and female body weights were performed with Systat (Systat Software, Inc., Point Richmond, CA).

Results and Discussion

Because the numbers of pheromone traps used increased during the season, numbers of predators sampled are presented as insects per trap (Fig. 1). The field population of *P. maculiventris* appeared to show two main peaks. The first, and more prominent peak was observed in June, followed by a less pronounced population peak in September. The two peaks probably correspond to two generations during the season. Adults that hibernated start field activity in March to April, and population numbers peak in June. The second peak in September indicates the second field generation.

Average body weights of female *P. maculiventris* were relatively constant during the sampling period (Fig. 2). Body weights are displayed together with four lines showing comparative weights of females reared in the laboratory under

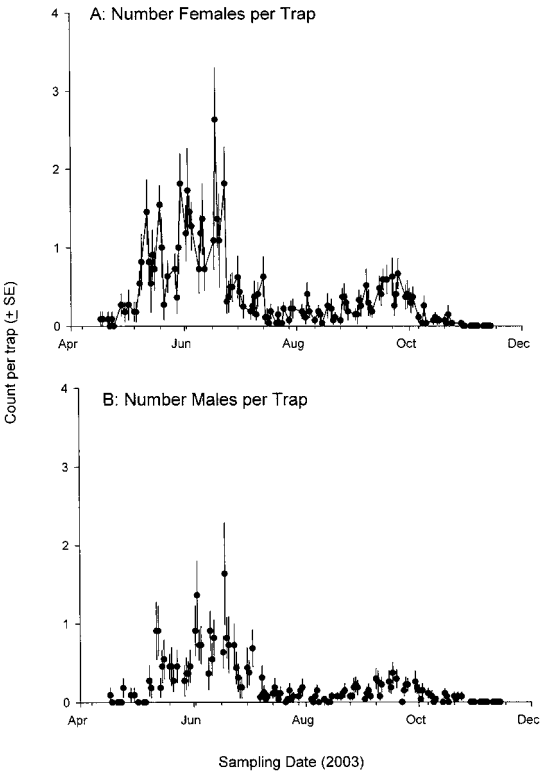

Fig. 1. Numbers of *Podisus maculiventris* collected per pheromone-baited trap ($\bar{x}$ ± SE) in muscadine grape vineyard, Leon Co., FL.

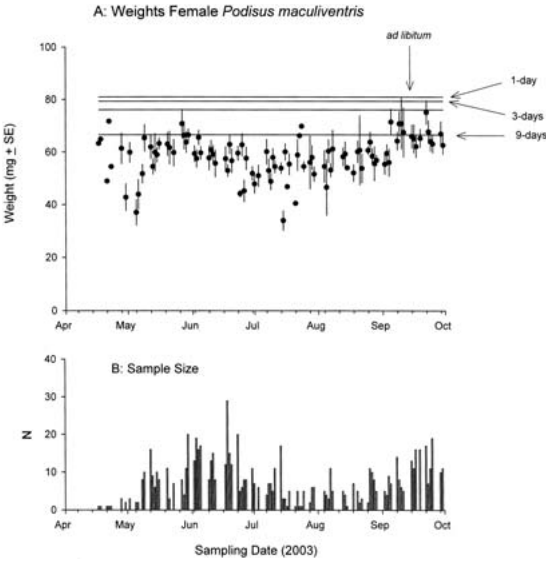

Fig. 2. Weights (mg) of female *Podisus maculiventris* ($\bar{x}$ ± SE) in grapes. A) Four lines indicate estimated mean laboratory weights of *P. maculiventris* in cultures fed *ad libitum*, and 1 prey item at intervals of 1, 3, and 9 days (Legaspi et al. 1996); B) Sample size obtained at sampling date, Leon Co., FL.

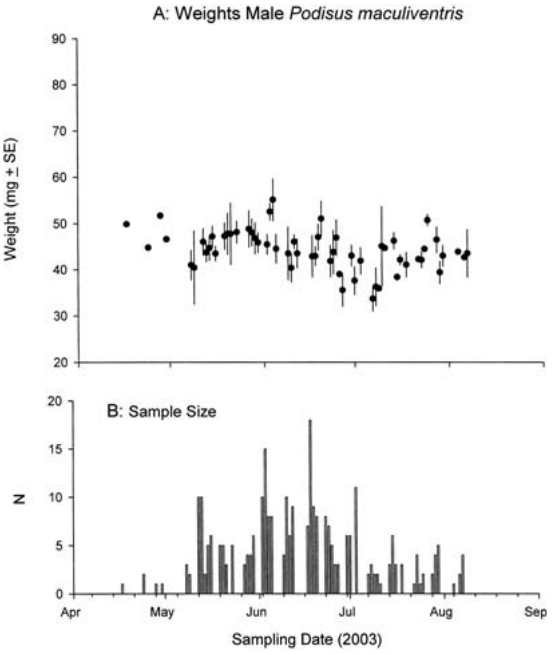

Fig. 3. Weights of male *Podisus maculiventris* (mg, $\bar{x}$ ± SE) in grapes, 2003, Leon Co., FL.

known feeding regiments. Legaspi et al. (1996) estimated that adult, unmated *P. maculiventris* females fed *ad libitum* (0 days between meals), and 1 prey item every 1-, 3-, and 5-days would weigh an estimated mean of 80.9, 79.3, 76.1, and 66.6 mg, respectively. These lines are superimposed on the field data. With few exceptions between 3- and 9-day feeding lines, the vast majority of the field population weighed less than the benchmark level of 66.6 mg, indicating low field predation rates. The present results are comparable to those obtained by Legaspi et al. (1996) for *P. maculiventris* in various crop systems in Indiana where female body weights were similar to laboratory females reared on a feeding regimen of 1 prey item every 3 to 9 days. Legaspi et al. (2004) used the same procedure to study field populations of *P. maculiventris* collected by pheromone traps from May to August 2003 in a muscadine grape vineyard at the Florida A&M University Center for Viticulture in Tallahassee, Florida. Field-collected females were found to have live body weights comparable to females fed less than one prey item every 9 days in the laboratory.

Body weights of males are shown for comparison (Fig. 3), although no similar studies have been performed on the effects of feeding regimens on body weights in the laboratory. Male body weights are known to be less than those of females under both laboratory and field conditions (Legaspi et al. 1996). These studies support the finding of low field predation rates in *Podisus maculiventris* (Wiedenmann & O'Neil 1992; and others).

Egg load dissections during the season are shown for mature, immature, and total eggs (Fig. 4). The numbers of immature eggs (Fig. 4b) indicate low numbers early in the season, followed by a subsequent increase, possibly due to ovigenesis in the field population. Insects that produce eggs after emergence are termed "synovigenic". The terminology was originally developed for parasitic Hymenoptera, but is applicable to other insects (Jervis & Kidd 1996; Jervis et al. 2001), although it had not been studied in predators previous to Legaspi & Legaspi (2004) (M. Jervis, Univ. Cardiff, personal communication). Recent laboratory data suggest that *P. maculiventris* is strongly synovigenic (Legaspi & Legaspi 2004). The present study may be interpreted as evidence for synovigeny in a field population of *P. maculiventris*. However, this conclusion is made with caution because of the presence of females without eggs (Fig. 4) and because the ages and individual histories of the specimens are unknown.

Legaspi & O'Neil (1994) determined that laboratory females with egg loads ≥25 corresponded to 15-d-old predators fed *ad libitum* to 1 prey item every 3 days. Conversely, predators with <25 eggs corresponded to 15-d-old females fed 1 prey item at intervals >3 days. Mean egg load of 25 was used as a benchmark by Legaspi et al. (1996) to characterize field populations and is superimposed on field egg loads in Fig. 4c. With the exception of a

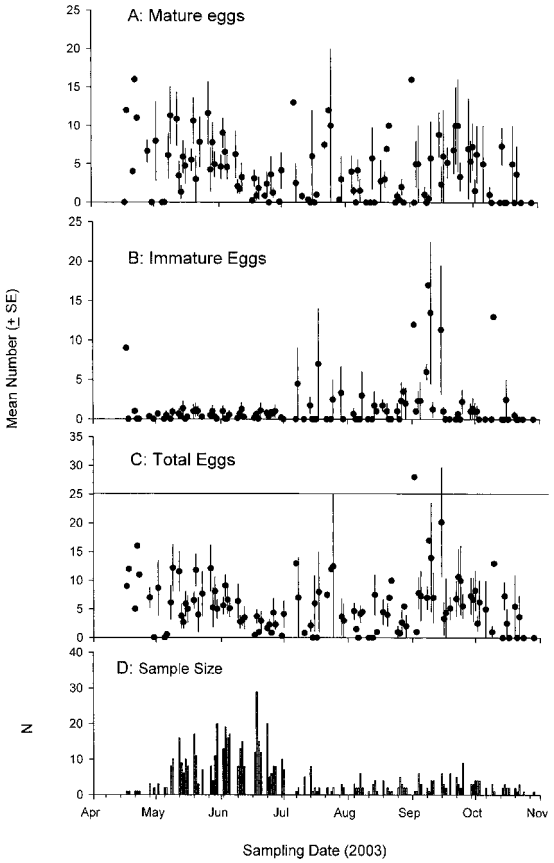

Fig. 4. Mean egg loads of female *Podisus maculiventris* (mg, $\bar{x}$ ± SE) in grapes. A) Mature eggs; B) Immature eggs, showing increasing numbers later in the season; C) Total eggs, line indicates 25 eggs which is the egg load of laboratory females fed 1 prey item every 3 days (Legaspi et al. 1996); D) Sample size obtained at sampling date, 2003, Leon Co., FL.

single observation, all egg loads were found below the benchmark line, possibly indicating low field predation rates. The sample sizes upon which all egg counts were based roughly correspond to the June and September peaks found for the field population (Figs. 4c and 1). Unlike body weights, it is more difficult to make inferences based on mean egg loads because of the confounding effects of feeding regimen and predator age. Age tends to increase egg load; food scarcity to decrease it. Both factors are largely unmeasured in our field populations. Legaspi & O'Neil (1994) also concluded that *P. maculiventris* exhibits continued egg development and storage until deposition, thereby suggesting a synovigenic predator.

Linear regressions of egg loads on female body weights gave the expected result that larger females had higher total numbers of mature and immature eggs (Fig. 5) (*TOTAL EGGS* = -10.92 + 0.277 *WEIGHT*; F = 170.9; *df* = 1, 580; $P < 0.01$; R^2 = 0.23). Regressions on numbers of mature eggs (*MATURE* = -9.2 + 0.23 *WEIGHT*), and immature eggs (*IMMATURE* = -1.79 + 0.045 *WEIGHT*;) were similarly significant ($F = 145.1$; *df* = 1, 577; $P < 0.01$; $R^2 = 0.2$; and $F = 38.1$; *df* = 1, 577; $P < 0.01$; $R^2 = 0.06$, respectively). The positive relationship we found between egg loads and female body weights has been amply documented. Jervis & Kidd (1996) cite numerous examples in the literature of positive relationships between female body size or weight and the following measures of reproduction: ovariole number (two references); egg load (18 references); and lifetime fecundity (nine references).

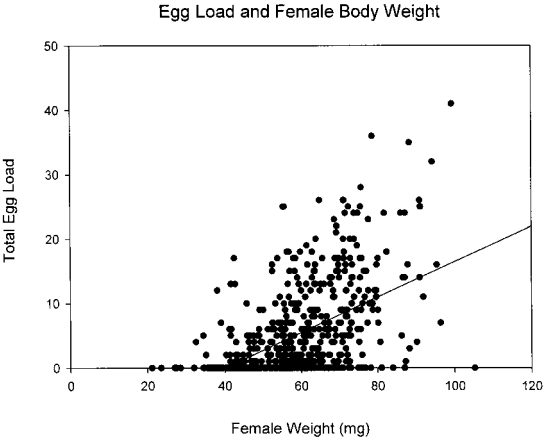

Fig. 5. Total egg load as a function of female body weight (mg). Line indicates linear regression: *TOTAL EGGS* = -10.92 + 0.277 *WEIGHT* ($P < 0.01$).

In conclusion, *P. maculiventris* probably has two field generations in Florida, which are not discrete due to the largely mild year-long climate and absence of severe winters. Mean female body weight in the field was similar to those obtained in various crops in Indiana, indicating low predation rates in both cases. Egg loads of field-collected females were comparable to those found in Indiana. The increase in numbers of immature eggs later in the season may be an indication of continued egg production in older females. This finding is expected given previous laboratory data showing that immature eggs are continuously produced throughout female lifetime. Larger females predictably had higher mean egg loads. The similarity in biological characteristics found in field populations of Indiana and Florida suggest that *P. maculiventris* plays similar roles in the suppression of pest insects by feeding on prey in low rates, despite the differences in crop and climate.

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NEW SPECIES OF *COCCOPHAGUS* WITH DENSELY SETOSE AXILLA FROM MEXICO (HYMENOPTERA: APHELINIDAE)

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ABSTRACT

Two new species of the genus *Coccophagus* from Mexico, *neocomperei* **sp. nov.** and *debachi* **sp. nov.** are described and illustrated. The *redini* species-group is proposed for the genus *Coccophagus*, based on three species with unusual setation on the axillae. A key to identify both sexes of members of the *redini* group is provided.

Key Words: Mexico, Hymenoptera, Aphelinidae, *Coccophagus*, new species

RESUMEN

Se describen e ilustran dos especies nuevas del género *Coccophagus* de México, *neocomperei* y *debachi*. Se propone el grupo de especies *redini* para el género *Coccophagus*, basado en tres especies con una disposición inusual de setas en las axilas. Se incluye una clave para la identificación de ambos sexos de los miembros del grupo *redini*.

Translation provided by author.

Coccophagus Westwood is one of the largest genera in the family Aphelinidae. Species of this genus are endoparasitoids of Coccoidea, mainly soft scales (Coccidae), and rarely mealybugs (Pseudococcidae). Males are generally hyperparasitoids on primary parasitoids, including conspecific females. Species of *Coccophagus* have been used successfully in biological control of pestiferous soft scales worldwide (Clausen 1978; Rosen & De Bach 1991). Over 200 species have been described worldwide. Sixty species are known to occur in the New World, including 39 species distributed in the Neotropics and 32 species distributed in the Nearctic region (Woolley 1997; Noyes 2002). Ten species are known to occur in Mexico (Myartseva & Ruíz-Cancino 2000; Noyes 2002; Myartseva & Coronado-Blanco 2003). Most of the species from the New World were described by H. Compere and L. O. Howard.

Two new species of *Coccophagus* are described in this article, both with unusual setation of the axilla. Only one species, *Coccophagus redini* Girault, with densely setose axillae was previously known. Girault (1924) described this species from one female collected in Australia, and it was later redescribed by Compere (1931). Abbreviations for depositories of the material examined: BNMH—Natural History Museum, London, U.K.; UAT—Universidad Autónoma de Tamaulipas, Ciudad Victoria, Tamaulipas, México; UCRC—University of California, Riverside, California, USA; USNM—National Museum of Natural History, Washington, D.C., USA.; ZISP—Zoological Institute of Academy of Sciences, Saint Petersburg, Russia.

Coccophagus neocomperei Myartseva & Ruíz, **sp. nov.** (Figs. 1-8)

Description

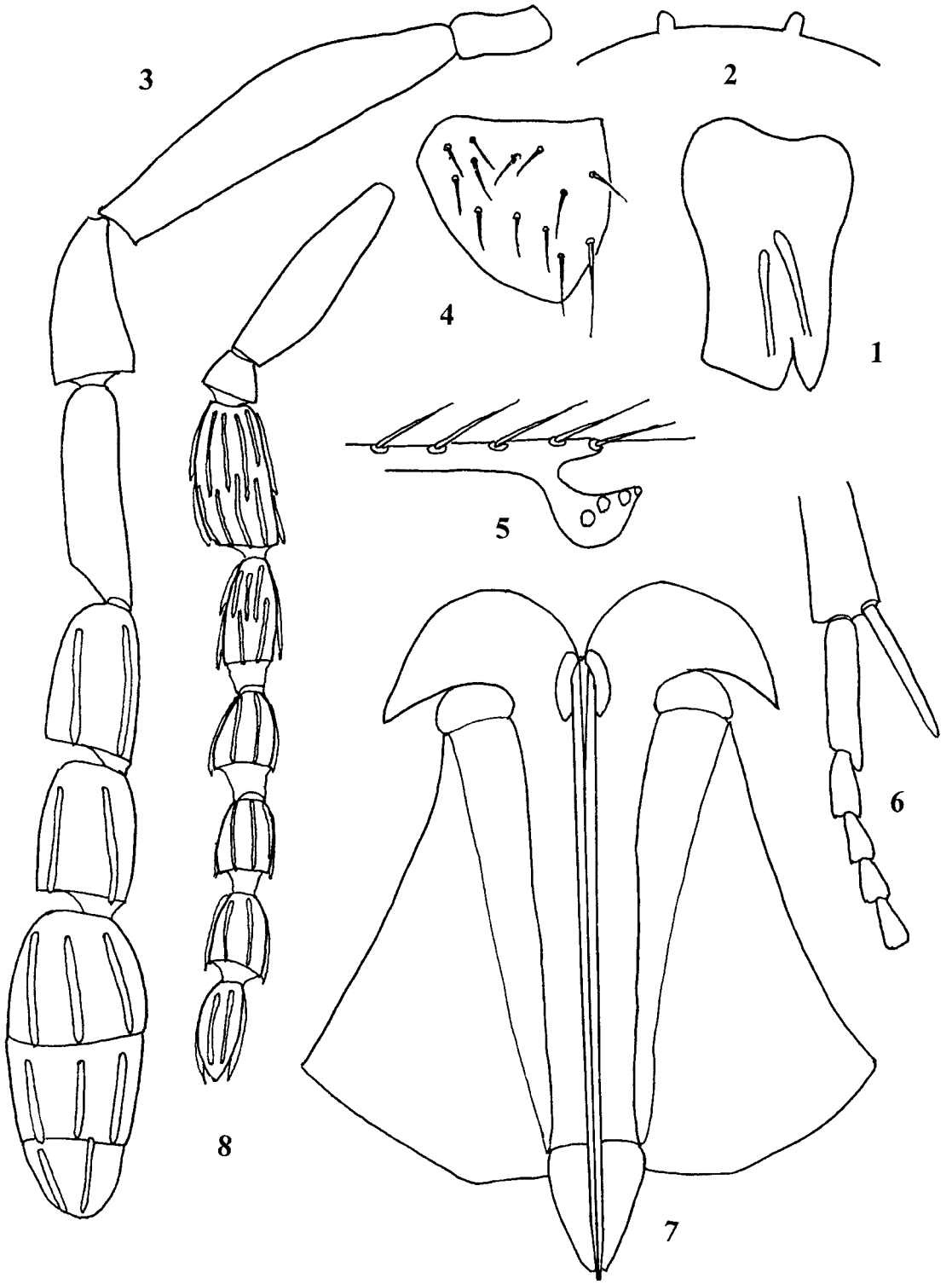
FEMALE. Length: 0.90-1.10 mm.

Coloration

Head light yellow, frontovertex yellow, occiput with black oval spots along foramen, antennal club and last two funicular segments very slightly infuscate. Mesosoma light yellow, pronotum black medially, mesoscutum with black anterior margin, outline of axillae black, propodeum black, on sides brownish-yellow (female from Campeche with white longitudinal stripe behind spiracle). Legs light yellow. Wings hyaline, venation of fore wing very slightly infuscate. Endophragma black. Metasoma whitish-yellow, third to seventh tergites black dorsally, ovipositor sheaths black.

Morphology

Head wider than mesosoma, slightly wider than high and less than 2× wider than length. Frontovertex slightly longer than wide, its width less than half of head width. Occipital margin straight. Ocelli in slightly obtuse triangle; hind ocelli subequal in distance from eyes and occipital margin. Eyes slightly more than 2× as long as cheeks. Mandible (Fig. 1) with one tooth and a broad dorsal truncation. Labial and maxillary palpi one- and two-segmented, respectively. Clypeus as in Fig. 2.



Figs. 1-8. *Coccophagus neocomperei*, **sp. nov.**, female: 1—mandible, 2—clypeus, 3—antenna, 4—axilla, 5—stigmal vein, 6—middle tarsus and tibial spur, 7—ovipositor; male: 8—antenna.

Antennae (Fig. 3) inserted lower than lower level of eyes. Distance between toruli very slightly longer than distance from torulus to eye. Radicula about 2× as long as wide. Scape slightly more than 4.5× as long as wide. Pedicel about 2× as long as wide. First funicular segment the longest, 3.7× as long as wide and 1.4× longer than pedicel. 2nd-3rd segments subequal in length, each 1.6-1.7× as long as wide. Club about 2× as long as wide and subequal in length to last two funicular segments combined. First funicular segment without sensilla, others with 2-3 sensilla each.

Mesoscutum wider than long. Midlobe of mesoscutum densely setose, each side lobe with 3 long setae, axillae (Fig. 4) with one long and 8-13 short setae. Scutellum shorter than mesoscutum, wider than long, with 3 pairs of long setae, 3rd pair the longest. Propodeum with short triangular prominence medially. Endophragma widely rounded on apex. Fore wing about 2.5× as long as wide, marginal fringe short, disk with thinner and shorter setae along apical margin (0.06× length of wing). Submarginal vein with 8 long setae, marginal vein about 1.7× longer than submarginal and with 8-10 long setae on lower margin. Stigmal vein as in Fig. 5. Hind wing about 4.5× as long as wide, marginal fringe about 0.3 of maximal width of wing; disk setation very short and thin. Midtibial spur (Fig. 6) slightly longer than basitarsus, which is shorter than remaining tarsal segments combined. Ovipositor (Fig. 7) about 0.7× as long as middle tibia; third valvula 0.2× as long as second valvifer.

MALE. Length: 0.8 mm.

Coloration

Similar to female, but head with frontovertex orange-yellow, antennae whitish-yellow and without infuscations, midlobe of mesoscutum blackish posteriorly, axillae and notauli black, scutellum blackish on posterior margin and sometimes on anterior margin also. Propodeum black, with white longitudinal curved stripe behind spiracle or more often with one white spot under spiracle. Hind coxae blackish near base.

Morphology

Frontovertex as long as wide, its width about half of head width. Ocelli larger and in more obtuse triangle. Eyes about 1.4× longer than cheeks. Antennae (Fig. 8) inserted at the level of lower margin of eyes. Scape about 3.7× as long as wide. Pedicel subtriangular, 1.3× wider than length. First funicular segment the longest and slightly swollen, about 2× as long as wide and 0.7× as long as scape. 2nd segment slightly shorter and about 2× as long as wide, 3rd segment 0.8× as long as second and about 1.5× as long as wide. Club 4× as long as wide and longer than the last two funicular segments combined. All funicular and claval segments with many sensillae, situated on 1st segment in 2-3 rows, on 2nd in 1-2 rows, on 3rd-6th in one row. Axillae with reticulate sculpture and with one long and 5-7 short setae. Fore wing 2× as long as wide. Basitarsus of middle leg subequal to the next two tarsal segments combined. Genitalia 0.4× as long as middle tibia.

Comments. *Coccophagus neocomperei* **sp. nov.** is similar to the Australian species *Coccophagus redini* Girault, the only other species with densely setose axillae, but it can be easily distinguished from this species by characters given in the key (see below).

Etymology. This new species in named in honor of chalcidologist Harold Compere who worked in the University of California, Riverside, USA, and described many species of *Coccophagus*, and authored the first species revision of *Coccophagus* of the world.

Material examined. Holotype: Female, reared from soft scale on *Leucaena* sp., Mexico, Guerrero, Acapulco, 12-VI-2000, S. N. Myartseva. Paratypes: 16 females, 3 males (card mount), 3 females, 4 males (slide mount), same date as holotype; Campeche, Cd. del Carmen, one female on card, 30-VII-1984 (G. Gordh) (UCRC, No. 54587); Veracruz, 85 km. S of Veracruz, 180-200 m, one male on card, 31-VII-1984 (G. Gordh) (UCRC, No. 54596).

Specimen deposition. Holotype (mounted on slide) and paratypes, one female from Campeche, one male from Veracruz, 6 females and one male from Guerrero (on cards) deposited in UCRC; 5 paratype females and one paratype male (on cards) deposited in USNM; 2 paratype females and 2 paratype males (on slides) deposited in BMNH; 5 paratype females and one paratype male (on cards) deposited in ZISP; one paratype female and 2 paratype males (on slides) deposited in UAT.

Coccophagus debachi
Myartseva & Ruíz, **sp. nov.** (Figs. 9-12)

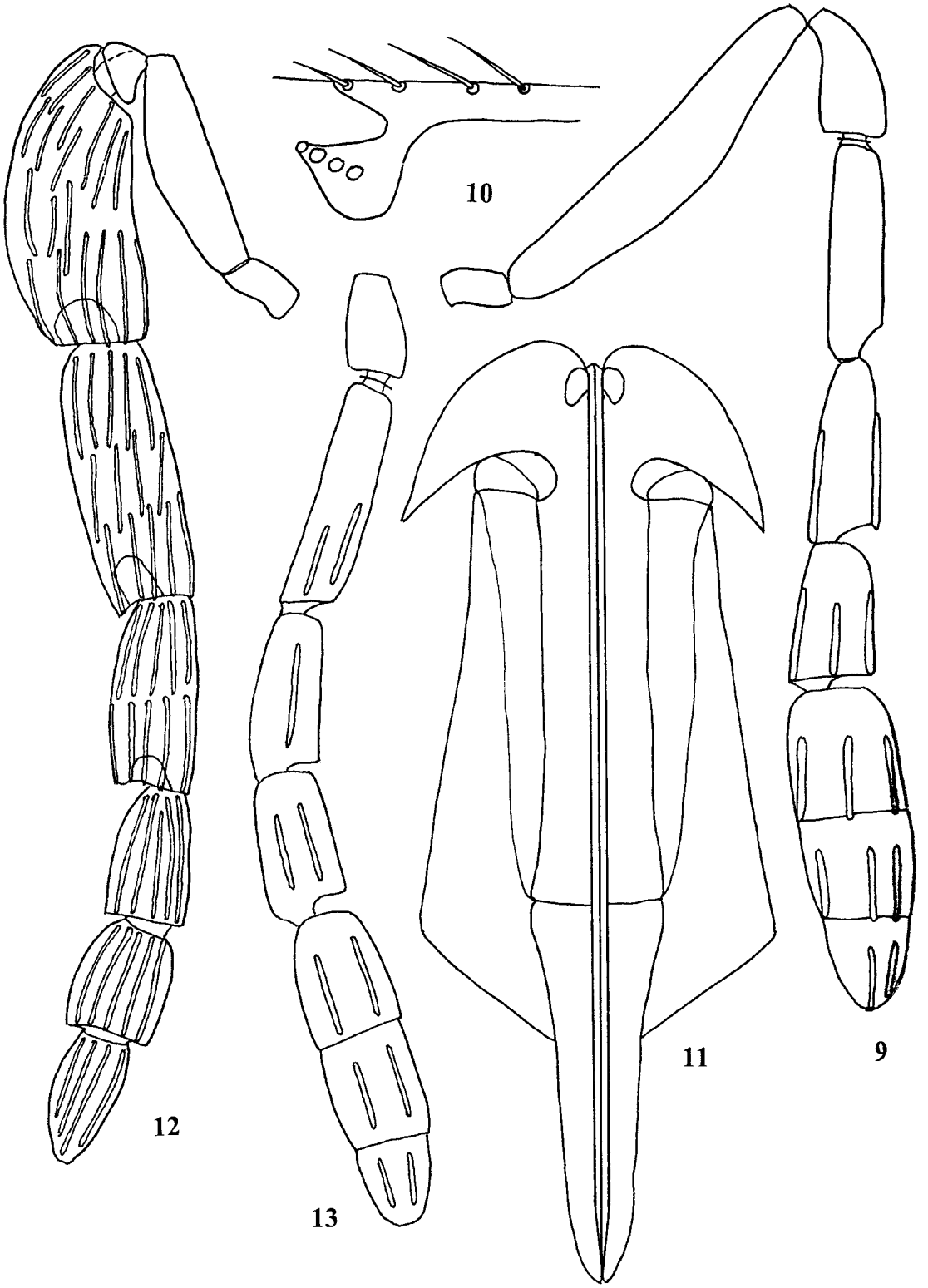
FEMALE. Length: 1.20-1.40 mm.

Coloration

Body coloration is very similar to *Coccophagus neocomperei* **sp. nov.**, but occiput without black oval spots along foramen, mesoscutum entirely light yellow, propodeum black with white longitudinal straight stripe behind spiracle on each side and metasoma with 4 to 6th tergites black dorsally.

Morphology

Head slightly wider than mesosoma and its own height and about 2× as wide as long. Fron-



Figs. 9-13. *Coccophagus debachi* **sp. nov.**, female: 9—antenna, 10—stigmal vein, 11-ovipositor; male:12—antenna. *Coccophagus redini*, female: 13—antenna (redrawn from Compere, 1931).

tovertex slightly wider than long, its width about half of head width. Ocelli in about rectangle triangle; hind ocelli separated from occipital margin by distance slightly longer than diameter of one ocellus and from eye margin by slightly longer distance. Eyes about 1.5× as long as cheeks. Mandible and clypeus as in *C. neocomperei*. Antennal scape (Fig. 9) 5× as long as wide. Pedicel 2× as long as wide. First funicular segment 4× as long as wide and 1.4× as long as pedicel. 2nd segment 0.7× as long as 1st and 2.5× as long as wide. Third segment 0.8× as long as 2nd and 1.5× as long as wide. Club about 2.5× as long as wide and slightly longer than two last funicular segments combined. First funicular segment without sensilla, others with 2-3 sensillae each. Axillae with 7-9 setae (one longer). Each side lobe with 3 long setae. Scutellum shorter than mesoscutum, wider than length, with 3 pairs of long setae. Propodeum with short triangular prominence medially. Endophragma widely rounded on apex. Fore wing 2.4× as long as wide, disk with thinner and shorter setae along apical margin (0.10 × length of wing). Submarginal vein with 10 long setae, marginal vein about 1.5× longer than submarginal vein and with 10 long setae on lower margin. Stigmal vein as in Fig. 10. Hind wing about 4.5× as long as wide, marginal fringe about 0.3× of maximal width of wing; disk setation very short and thin. Midtibial spur slightly longer than basitarsus, which is subequal in length to all remaining tarsal segments combined. Ovipositor (Fig. 11) slightly exserted, 0.9× as long as middle tibia; third valvula 0.7× as long as second valvifer.

MALE. Length: 1.10-1.20 mm.

Coloration

Similar to female, but frontovertex yellow, occiput with black oval spots along foramen, antennae whitish-yellow and without infuscation, midlobe of mesoscutum widely blackish distad, scutellum blackish basally and apically. Hind coxae blackish. Metasoma with 3rd-7th tergites black dorsally.

Morphology

Frontovertex slightly wider than long, its width slightly more than half of head width. Ocelli larger than in female and in obtuse triangle; hind ocelli separated from eye margin by distance of diameter of one ocellus and slightly longer than that from occipital margin. Eyes 2.7× as long as cheeks. Antennae (Fig. 12) inserted at the level of lower margin of eyes. Scape 3.4× as long as wide. Pedicel about 1.6× wider than long. First funicular segment the longest, swollen, about 2× as long as wide and 1.3× as long as scape, 2nd segment shorter and also 2× as long as wide. 3rd segment 0.8× as long as second and slightly less than 2× as long as wide. Club 3.6× as long as wide and shorter than the last two funicular segments combined. All flagellar segments with many sensillae. Axillae with reticulate sculpture and with 7-8 setae (one longer). Fore wing about 2.4× as long as wide, disk setation as in female. Submarginal vein with 9 long setae. Marginal vein longer than submarginal. Midtibial spur slightly longer than basitarsus, which is subequal in length to next three tarsal segments combined. Genitalia 0.6× as long as middle tibia.

Comments. *Coccophagus debachi*, **sp. nov.** is similar in coloration and morphology to the new Mexican species *C. neocomperei*. Females of both species can be distinguished by the following characters: *C. debachi* has occiput pale yellow, third gastral tergite pale yellow, propodeum with white longitudinal straight stripe behind spiracle on each side, second funicular segment 2.5× as long as wide, third segment 0.8× as long as the second, club about 2.5× as long as wide, ovipositor 0.9× as long as middle tibia, and third valvula 0.7× as long as second valvifer (Fig. 11). *Coccophagus neocomperei* has occciput with black elongate spot on sides of foramen, third gastral tergite black dorsally, propodeum brownish-yellow on sides, second funicular segment 1.7× as long as wide, third segment subequal to the second, club about 2× as long as wide, ovipositor 0.7× as long as middle tibia, and third valvula 0.2× as long as second valvifer (Fig. 7). Males of both species can be distinguished by the following characters: *C. debachi* has the first funicular segment longer than scape, second to fifth flagellar segments decreasing in length distally (Fig. 12) and genitalia 0.6× as long as middle tibia, whereas *C. neocomperei* has the first funicular segment shorter than scape, second to fifth flagellar segments subequal in length (Fig. 8), and genitalia 0.4× as long as middle tibia.

Etymology. This species is named in honor of American entomologist Paul De Bach, who collected this new species in Mexico. His material for our study was loaned from the Entomological Research Museum, University of California, Riverside, USA, including specimens: NN 54579-54580, 54582-54586, 54588-54591, 54593-54595.

Material examined. Holotype: Female, collected in pan trap, Mexico, Baja California Sur, Las Barracas, ca. 30 km E of Santiago, 20-IV-1984 (coll. P. De Bach) (No. 54583), deposited in UCRC. Paratypes (same data as the holotype) are deposited: one female on slide, 23-IV-1984 (No. 54588), two females on cards, 5-II-1984 (No. 54585), 20-IV-1985 (No. 54582) and one male on card, 30-IV-1985 (No. 54590), one male on slide, 1-VI-1985 (No. 54592) (all UCRC); two females on cards, 4-VI-1985 (No. 54584), 15-VI-1985 (No. 54586) and one male on card, 27-V-1986 (No. 54591)—in USNM; one female and one male on cards, 21-IV-1986 (No.54589, 12-VI-1986 (No. 54594)—in

BMNH; one female and one male on cards, 5-V-1986 (No. 54579), 12-VI-1986 (No. 54595)—in ZISP; one female and one male on cards, 5-V-1986 (No.54580), 1-VI-1985 (No.54593)—in UAT.

Discussion

According to Compere (1931), Annecke and Insley (1994), and Hayat (1998), seven species-groups are recognized in the genus *Coccophagus*: *lycimnia*, *ochraceus*, *malthusi*, *pseudococci*, *tschirchii*, *varius*, and *zebratus*-groups. We propose a new species-group, the *redini*-group, for three species: *C. redini* Girault, 1924 from Australia and the two new species from Mexico described herein, *C. neocomperei* and *C. debachi*. Species of this group differ from other known species-groups mainly by their unusual axillae, which are densely setose, including one longer seta. Species in the *redini*-group are similar to those of the *ochraceus*-group in that the funicle segments have excentric articulations, propodeum with median triangular prominence, stigmal vein swollen, body bicolored; but in species of the *redini*-group, females have the first funicular segment without sensillae, fore wing apically with thinner and shorter setae, and males have the first funicular segment swollen, curved and the largest.

Key to the Species of *Coccophagus* of the *redini*-group

1. Females 2

—Males 4

2. Pronotum entirely black, gaster entirely blackish. First funicular segment with sensilla (Fig. 13) . . . . . *redini* Girault

—Pronotum and gaster partly pale yellow. First funicular segment without sensilla (Figs. 3, 9) 3

3. Occiput pale yellow. 3rd gastral tergite pale yellow. Propodeum with white longitudinal straight stripe behind spiracle on each side. 2nd funicular segment 2.5× as long as wide, 3rd segment 0.8× as long as 2nd. Club about 2.5× as long as wide. Ovipositor 0.9× as long as middle tibia, third valvula 0.7× as long as second valvifer (Fig. 11) . . . . . *debachi* **sp. nov.**

—Occiput with black elongate spot on sides of foramen. 3rd gastral tergite black dorsally. Propodeum brownish-yellow on sides. 2nd funicular segment 1.7× as long as wide, 3rd segment subequal to 2nd. Club about 2× as long as wide. Ovipositor 0.7× as long as middle tibia, third valvula 0.2× as long as second valvifer (Fig. 7) . . . . . *neocomperei* **sp. nov.**

4. First funicular segment longer than scape. 2nd-5th flagellar segments decreasing in length distally (Fig. 12). Genitalia 0.6× as long as middle tibia . . . . . *debachi* **sp. nov.**

—First funicular segment shorter than scape. 2nd-5th flagellar segments subequal in length (Fig. 8). Genitalia 0.4× as long as middle tibia . . . . . *neocomperei* **sp. nov.**

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COMPARATIVE DEVELOPMENT AND COMPETITIVE ABILITY OF *DIBRACHYS PELOS* (HYMENOPTERA: PTEROMALIDAE) ON VARIOUS POTENTIAL HOSTS

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ABSTRACT

Dibrachys pelos (Grissell) is an occasional gregarious ectoparasitoid of *Sceliphron caementarium* (Drury). We report the second record of this host association, collected in western Nebraska, and present results of laboratory experiments on host suitability and utilization. When *D. pelos* was reared alone on prepupae of 6 possible hosts, 4 proved entirely suitable: the mud dauber wasps *Sceliphron caementarium* and *Trypoxylon politum* Say, and two of their parasitoids, a velvet ant, *Sphaeropthalma pensylvanica* (Lepeletier) and a bee fly, *Anthrax* sp. On these hosts *D. pelos* completed development in 2-4 weeks, with average clutch sizes of 33-57, of which 24.7% were males. The other two hosts tested, the flesh fly *Neobellieria bullata* (Parker) and the leaf-cutter bee *Megachile rotundata* (Say), proved marginal, with very few adult progeny produced. When reared on these same 6 hosts with the addition of a competing parasitoid, *Melittobia digitata* Dahms, *D. pelos* fared poorly, being the sole offspring producer in at most 30% of the trials (on *Anthrax* hosts) and failing to prevail at all on *T. politum* hosts. Comparative data on host conversion efficiency indicated that *M. digitata* was more efficient than *D. pelos* on every host except *Anthrax*.

Key Words: host conversion efficiency, interspecific competition, *Melittobia digitata*

RESUMEN

Dibrachys pelos (Grissell) es un ectoparasitoide gregario ocasional de *Sceliphron caementarium* (Drury). Reportamos el segundo registro de este parasitoide asociado al mencionado hospedador, colectados en el oeste de Nebraska. Se presentan los resultados de experimentos de laboratorio acerca de la utilización y conveniencia de hospedadores por *D. pelos*. Al criarlo sobre prepupas de seis posibles hospedadores, cuatro resultaron altamente convenientes: las avispas de nidos de barro *Sceliphron caementarium* y *Trypoxylon politum* Say, así como sus parasitoides, la hormiga de terciopelo *Sphaeropthalma pensylvanica* (Lepeletier) y la moscaabeja *Anthrax* sp. *D. pelos* completó su desarrollo sobre estos hospedadores en 2-4 semanas, con una descendencia promedio entre 33-57 individuos, de los cuales el 24.7% fueron machos. Los otros dos hospedadores utilizados, la mosca *Neobellieria bullata* (Parker) y la abeja *Megachile rotundata* (Say), fueron marginales en eficiencia, produciendo una progenie reducida. Al agregar *Melittobia digitata* Dahms como competidor, en crías sobre estos mismos hospedadores, *D. pelos* lo hizo pobremente, ganando, como máximo, solo en 30% de los ensayos (sobre *Anthrax*) y fallando totalmente sobre *T. politum*. Datos comparatives sobre la eficiencia de conversión del hospedador como único productor de progenie mostró que *M. digitata* fue más eficiente que *D. pelos* sobre cada hospedador excepto sobre *Anthrax* sp.

Translation provided by the authors.

Mud dauber wasps (Hymenoptera: Sphecidae) of the widely distributed genera *Trypoxylon* and *Sceliphron* share a complex ecological web of inquilines that either parasitize them or use their nests (Matthews 1997). Habits, prey, and inquilines are particularly well known for the organ pipe mud dauber, *Trypoxylon politum* Say (Barber & Matthews 1979; Brockmann & Grafen 1989; Cross et al. 1975; Molumby 1995; Volkova et al. 1999) and the yellow-and-black mud dauber, *Sceliphron caementarium* (Drury) (Shafer 1949; Hunt 1993).

In addition to heavy parasitism by *Melittobia* (Hymenoptera: Eulophidae) wasps and sarcophagid and bombylid flies, both mud dauber species also have other parasitoids that are less commonly encountered (Matthews 1997a). One of the latter is *Dibrachys pelos* Grissell (Hymenoptera: Pteromalidae) (Fig. 1a), an ectoparasitoid apparently distributed across North America (Grissell 1974) but infrequently collected. The only published record of *D. pelos* as a member of the mud dauber "community" is that of Grissell (1974). Despite an extensive survey of trap-nesting wasps and bees and their inquilines (mainly from the eastern United States), Krombein (1967) found no associated *Dibrachys* species. In our own wide-ranging collections of mud dauber nests east of

the Mississippi River and particularly in the southeastern US over the last 20 years, we have never before found *D. pelos*.

Grissell (1974) reared this species on prepupae of *S. caementarium* and other hosts, but little is known of its natural host preferences or possible competition with other parasitoids. Elsewhere, other *Dibrachys* species have been reported to parasitize various families of Hymenoptera and Diptera (Floate et al. 1999; Smith & Rutz 1991; Urban & Eardley 1995; Whiteman & Landwer 2000), suggesting that *D. pelos* may be an opportunistic polyphagous parasitoid capable of attacking a variety of host species.

Field collection of a *Sceliphron caementarium* nest that was parasitized by *D. pelos* enabled us to investigate the latter species' ability to parasitize other potential hosts. In order to better understand its apparent rarity as a parasitoid of mud dauber wasps, we also staged interspecific competition studies with *Melittobia digitata* Dahms, one of the most common parasitoids of mud dauber wasps.

Materials and Methods

Three cells of a S*celiphron caementarium* nest collected by RWM at Lake McConaughy, Keith Co., Nebraska on June 21, 2003 contained pupae and recently emerged adults of *Dibrachys pelos*. These were brought to our laboratory at the University of Georgia, Athens, GA and reared for one generation on *S. caementarium* prepupae.

To investigate relative suitability of additional common potential hosts, individual 2-day-old mated female progeny from this *D. pelos* culture were placed on prepupae of 5 species known to be acceptable hosts for *M. digitata*: *T. politum* Say, the leaf-cutter bee, *Megachile rotundata* Say (Hymenoptera: Megachilidae), the flesh fly *Neobellieria bullata* Parker (Diptera: Sarcophagidae), the velvet ant *Sphaeropthalma pensylvanica* (Lepeletier) (Hymenoptera: Mutillidae), and a bee fly *Anthrax* sp. (Diptera: Bombyliidae). The first 3 species have been routinely used as hosts in other studies on *M. digitata* (González & Matthews 2002; Silva-Torres & Matthews 2003) and are available readily; the last 2 species are themselves parasitoids of *T. politum* (Cross et al. 1975; Matthews 1997a, b). Concurrently, parallel cultures of *D. pelos* were maintained on *S. caementarium*. Ten replicates of each host species were used in all experiments except for *Sph. pensylvanica*, for which only 3 prepupae were available. All cultures were maintained at 25°C, 65% RH. Development time, progeny production, sex ratio, and host use (suitability) were recorded.

To investigate potential interspecific competitive interactions, an additional 10 replicates were concurrently established on each host (except *Sph. pennsylvanica* due to limited availability). For these we simultaneously placed one mated 2-day-old female each of *D. pelos* and *M. digitata* on the host, and maintained these under the same conditions as the other cultures. Outcomes of these competition experiments were scored as won (only *D. pelos* adults emerged), lost (only *M. digitata* adults emerged), or coexistence (adults of both parasitoids emerged). Number of adult progeny emerging and their sex ratio, were also recorded. We did not conduct a parallel series of intraspecific competition experiments (2 females of *D. pelos* on each host).

As one indicator of the relative suitability of the various hosts, host conversion efficiency values (analogous to feed conversion efficiencies for poultry or pork) were calculated for both *D. pelos* and *M. digitata*. To do this, samples of 10 males and 10 females of each parasitoid species were individually weighed on a Mettler® balance and the average weight of a single female and male of each species was determined. Ten individuals of each of the various hosts were also weighed to obtain an average host weight. The average number of males and females reared from each host when each of the parasitoids were alone was multiplied by the individual wasp's average weight, this being apportioned according to the average sex ratio obtained when reared alone on the respective hosts. This value was then divided by the average host weight and the result multiplied by 100 to give a percent, the host conversion efficiency.

Results and Discussion

Host Suitability and Development Time

Grissell (1974) reported that *D. pelos* laid eggs on prepupae of *Sceliphron*, as well as *Ancistrocerus* and *Euodynerus* (Hymenoptera: Vespidae, Eumeninae), and *Megachile pacifica*, but completed development only in the first 2 hosts. In our experiments, *D. pelos* oviposited also on at least some of all hosts offered (Table 1).

The most successful development occurred with 4 taxonomically diverse but ecologically related species—the mud daubers *S. caementarium* and *T. politum*, and their parasitoids, the velvet ant *Sph. pensylvanica* and the bee fly, *Anthrax* sp. (Fig. 1c); all individuals (100%) of these host species were parasitized successfully, as defined by emergence of *D. pelos* adult progeny. Development times on these 4 preferred hosts were quite similar, requiring 1-3 days for eggs, 7-14 days for larvae, and 7-12 days for pupae, with the total development time ranging from 16-27 days. These ranges for each developmental stage are consistent with data for *D. pelos* on *S. caementarium* reported by Grissell (1974).

Although some eggs were laid on *Megachile rotundata* and *N. bullata* hosts, most immature *D. pelos* perished, so that on average fewer than

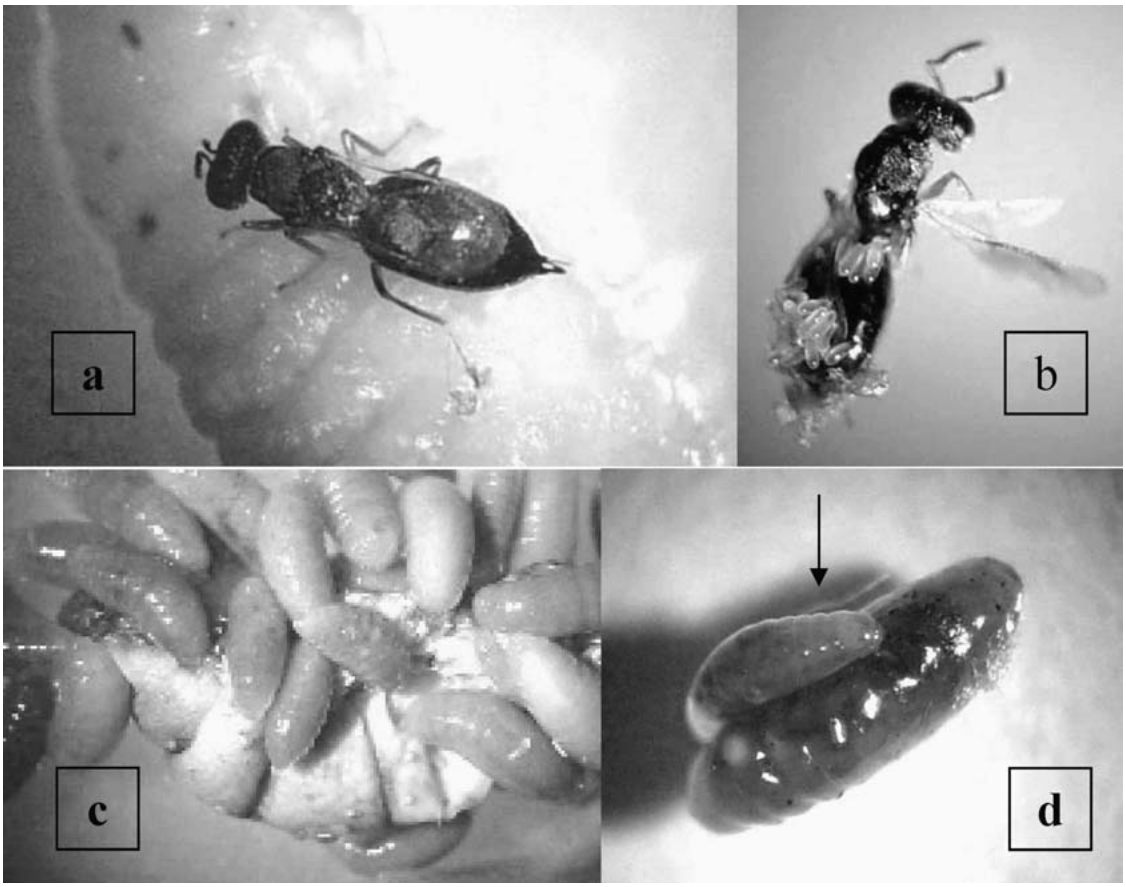

Fig. 1. (a) *Dibrachys pelos* female on prepupa of *S. caementarium*; body length of adult female *D. pelos* = 3 mm; (b) Eggs of *M. digitata* on abdomen of newly eclosed adult *D. pelos*; (c) Gregarious larvae of *D. pelos* feeding on *Anthrax* sp. (Diptera: Bombyliidae); (d) Larva of *M. digitata* (arrow) feeding on larva of *D. pelos*.

4 adults eclosed from these 2 hosts (Table 1). Furthermore, the life cycle took significantly longer to complete on these "marginal" hosts. For example, whereas *D. pelos* started laying eggs on most hosts within 24 hours, oviposition was delayed for up to 4 days on *N. bullata*. Development was also strikingly slower on *N. bullata* at every stage with the result that adults emerged only after 24 to 36 days, compared to 16-27 days on the 4 preferred hosts. Development was also somewhat slower on *Megachile*, requiring from 19-31 days. Grissell (1974) attempted to rear *D. pelos* on *Megachile pacifica*, and obtained progeny on 19 of 71 hosts. However, 75% of the eggs laid on *M. pacifica* prepupae failed to complete development to adults. Similarly, we noted significant larval mortality on *M. rotundata* hosts and the few adult progeny obtained were on only 3 of the 10 host replicates.

Comparable data for the progeny of *M. digitata* on the same suite of hosts (except *Sphaeropthalma*, unpubl. data) showed that all hosts were acceptable with adults of both sexes reared from 100% of the replicates (n = 10 for each host).

Sex Ratios

Grissell (1974) reported male-biased sex ratios for *D. pelos* on *Sceliphron* and *Ancistrocerus.* In contrast, we obtained female-biased sex ratios in nearly every trial on every host (Table 1). These ratios appeared to vary with the host species. On the 4 most successful host species, *D. pelos* produced an average of 24.7% males; on the two "marginal" hosts, 43% were male. Overall, the smallest host species (*M. rotundata*) yielded the highest proportion of males (48%). The 13% on *Neobellieria bullata* is probably not representative, as it was based on very few individuals.

Interspecific Competition

In our staged competition experiments with one female each of *D. pelos* and *M. digitata* on a

TABLE 1. OFFSPRING PRODUCTION (MEAN ± SD) AT 25°C, 65% RH BY *D. PELOS* ON VARIOUS HOSTS, ALONE, AND FOR THE THREE POSSIBLE COMPETITIVE OUTCOMES WITH *M. DIGITATA* (*N* = 10).

Host species	Experiment	No. of hosts parasitized	No. of adult progeny produced (Mean ± SD)		Sex ratio (% males)
			Males	Females	
		Successful hosts			
Sceliphron caementarium	Alone	10/10	14.5 ± 6.5	31.3 ± 12.1	32
	Competition "winner"	1/10	26	25	51
	Competition "loser"	7/10	0	0	0
	Coexistence	2/10	5.5 ± 6.4	12 ± 8.5	31.4
Trypoxylon politum	Alone	10/10	12.9 ± 7.6	44.3 ± 15.8	23
	Competition "winner"	0/10	0	0	—
	Competition "loser"	9/10	0	0	0
	Coexistence	1/10	1	3	25
Sphaeropthalma pensylvanica	Alone**	3/3	6.3 ± 1.2	26.7 ± 10.0	19
Anthrax sp.	Alone	10/10	13.6 ± 2.7	39.9 ± 4.2	25
	Competition "winner"	3/10	16.3 ± 10.2	20.3 ± 7.0	45
	Competition "loser"	4/10	0	0	0
	Coexistence	3/10	7.3 ± 3.8	13 ± 6.0	36
		Marginal hosts*			
Megachile rotundata	Alone	3/10	3 ± 2.6	3.3 ± 3.5	48
	Competition "winner"	1/10	2	1	67
	Competition "loser"	3/10	0	0	0
	Coexistence	0/10***	0	0	0
Neobellieria bullata	Alone	5/10	0.4 ± 0.5	2.6 ± 0.5	13
	Competition "winner"	0	0	0	—
	Competition "loser"	9/10	0	0	0
	Coexistence	0/10***	0	0	0

*Marginal hosts are those on which *D. pelos* managed to produce a few adult progeny in fewer than half of the 10 competition replicates.

**Limited number of available hosts did not allow use in competition trials.

***In 6 replicates with *Meg. rotundata* hosts and 1 replicate with *N. bullata* hosts, no adult progeny of either competitor were produced.

host, the 2 females seldom coexisted successfully. Only in 2 replicates with *Sceliphron*, 1 replicate with *Trypoxylon*, and 3 replicates with *Anthrax* were hosts successfully shared, as defined by the subsequent appearance of adult offspring of both sexes of both species (Table 1, coexistence). Overall, *D. pelos* was the loser in the competition experiments, producing no adult progeny in 20 of the 30 trials with the three hosts preferred by females alone (Table 1).

These outcomes were not simply related to host size. Despite being the smallest of the 3 preferred hosts, *Anthrax* was the most likely to be shared (3 replicates), but *D. pelos* also was the outright competition winner in 3 replicates and the loser in 4 replicates. However, on *Sceliphron* sharing occurred in 2 of 10 trials; in 7 trials, *Melittobia* were the sole progeny to emerge as adults, and in 1 trial, only *Dibrachys* adults emerged. On *Trypoxylon*, the largest hosts, 9 of the replicates resulted in only *Melittobia*, and in only 1 trial did adults of both species emerge.

When *D. pelos* won the competition on *Anthrax* hosts the number of males emerging was not different than when alone (no competitor), but the number of females emerging was fewer than when alone (Student's *t*-test, males $P = 0.69$, females $P = 0.04$). When both *D. pelos* and *M. digitata* adults emerged after competition for an *Anthrax* host, the number of *D. pelos* females was again fewer than when *D. pelos* was alone (Student's *t*-test, $P = 0.005$), but not when compared to when it won outright (Student's *t*-test, $P = 0.24$). Reduced numbers of progeny in competitive situations is not surprising since the host resource is not unlimited and, when shared, both host quality and quantity decline due to host feeding by each of the female parasitoids.

One straightforward reason why *D. pelos* suffers most from this competitive interaction was immediately apparent when larvae of *M. digitata* were observed feeding upon *D. pelos* larvae (Fig. 1d). Subsequently, emerged *M. digitata* were observed laying eggs directly upon pupae and even

TABLE 2. CONVERSION EFFICIENCY* OF *DIBRACHYS PELOS* AND *MELITTOBIA DIGITATA* REARED ON DIFFERENT HOSTS; BASED ON MEANS FOR $N = 10$.

Host species	Weight (g) (Mean ± SD)	Conversion Efficiency Index (%)	
		D. pelos	*M. digitata*
Suitable hosts for *D. pelos*			
S. caementarium	0.14 ± 0.003	22.5	25.5
T. politum	0.30 ± 0.006	13.7	21.2
Anthrax sp	0.25 ± 0.005	15.3	13.3
Marginal hosts for *D. pelos*			
M. rotundata	0.03 ± 0	13.1	17.3
N. bullata	0.1 ± 0.01	2.3	13.6; 15.9**; 15.3***

*Conversion efficiency = (total number of adult offspring x individual body weight)/ host weight × 100; average weights of individuals were for *D. pelos* (males = 0.42 mg, females 0.80 mg) and for *M. digitata* (males 0.16 mg, females 0.12 mg). Further explanation in text.

**Data from Silva-Torres and Matthews (2003), $n = 4$, host weight = 0.11 g

***Data from Randall and Guinan (unpubl.), $n = 23$, host weight = 0.12 g.

on newly emerged adults (Fig. 1b); in the former case the larvae developed into adult wasps, but larvae perished in the latter case. Depending on the host, *M. digitata* complete development to adults in 14-24 days (González & Matthews 2002), somewhat more rapid than *D. pelos* development in this study.

Differences in fecundity on these hosts may provide equally or more important explanations for this disparity. A single *M. digitata* female on a *Trypoxylon* host produces an average of 458 females and 13 males (unpubl. data), whereas a single *D. pelos* female produces the same number of males but about 10 times fewer females (Table 1). Similar disparities exist for the other hosts, although *M. digitata* is more broadly polyphagous (Dahms 1984) and successfully reproduces large clutches of progeny on both of the hosts that proved only marginally suitable for *D. pelos*.

In the 5 experiments (total from all hosts) where *D. pelos* "won" in competition against *M. digitata*, the proportion of *D. pelos* males increased substantially from that obtained for a female ovipositing in the absence of competition (Table 1). In the 6 replicates (total from all hosts) where adults of both parasitoids emerged, *D. pelos*' sex ratios remained similar to those obtained for *D. pelos* females alone on hosts, although the proportion of males was elevated for *Anthrax* hosts. However, small sample sizes and low numbers of progeny in the competition treatments make it difficult to draw definitive conclusions.

So why does *D. pelos* appear to be relatively rare in field collections of mud dauber nests? In addition to its poor success in our staged competitions for hosts, it may be physiologically less efficient in converting host biomass to parasitoid progeny. To gain a perspective on this possibility, we compared the host conversion efficiency of *D. pelos* and *M. digitata* on each of the hosts used in these experiments (Table 2). *Melittobia digitata* were more efficient on every host tested but *Anthrax*. This suggests that perhaps the hosts we tested were less suitable for *D. pelos* development. Perhaps *D. pelos* is better adapted to twig-nesting wasps or some other unknown host, and its occurrence on *S. caementarium* was strictly opportunistic and facultative at sites not concurrently colonized by *Melittobia*. (In our extensive field collections of *S. caementarium* and *T. politum* nests over several years in eastern N. America, *Melittobia* is by far the commonest parasitoid found [unpubl. data].). In support of this it is notable that in the extensive sample of mud dauber nests taken from the same bridge in Nebraska where *D. pelos* was originally collected failed to turn up any *Melittobia*.

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HELICOVERPA ZEA (LEPIDOPTERA: NOCTUIDAE) DYNAMICS AND PARASITISM IN MARYLAND SOYBEANS

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ABSTRACT

Larval populations of the corn earworm, *Helicoverpa zea* (Boddie), were surveyed in soybeans from 1995 to 1997 to catalogue larval parasites and quantify rates of parasitism. In addition, the relationship between moth captures in black-light traps and larval densities in soybeans was examined. Parasitism was consistently high throughout the region averaging 80.3%, 82.3%, and 73.1% for all dates in 1995, 1996, and 1997, respectively, and appeared to suppress *H. zea* populations. The predominate parasite species was *Microplitis croceipes* (Cresson) with some parasitism by *Cotesia marginiventris* (Cresson), *Meterous autographae* Meusebeck, and *Winthemia rufopicta* (Bigot). The date of the peak weekly capture of moths explained 99.7% of subsequent larval densities in soybeans, while the average weekly moth catches did not. The earlier moth peak in 1995 corresponded with higher populations of larvae, while the later peaks in 1996 and 1997 were followed by very low, sub-economic larval populations. Departures from normal for precipitation and temperature during August explained 99.8% and 95.3%, respectively, of the variation in the date of peak moth capture.

Key Words: *Helicoverpa zea*, soybeans, parasitism, black-light traps, Lepidoptera

RESUMEN

Las poblaciones de las larvas del gusano del elote, *Helicoverpa zea* (Boddie), fueron muestreadas en soya desde 1995 hasta 1997 para catalogar los parasitos de larvas y cuantificar la tasa de parasitismo. Además, la relación entre las polillas capturadas en trampas de luz negra y la densidad de las larvas fueron examinadas. El parasitismo fue consistentemente alto atravéz de la región con un promedio de 80.3%, 82.3%, y 73.1% para las fechas en 1995, 1996, y 1997, respectivamente, y aparentemente con ello delimito las poblaciones de *H. zea*. La especie de parasito predominante fue *Microplitis croceipes* (Cresson) seguido con el parasitismo por parte de *Cotesia marginiventris* (Cresson), *Meterous autographae* Meusebeck, y *Winthemia rufopicta* (Bigot). La fecha correspondiente al número mas alto de polillas capturadas explica 99.7% de las densidades de larvas subsecuentes sobre la soya, mientras que el promedio semanal de las polillas capturadas no lo indica. El pico de la población mas temprana en 1995 correspondio con poblaciones mas altas de las larvas, mientras que los picos mas tardes de la población en 1996 y 1997 fue seguidos con poblaciones sub-económicas de larvas muy bajas. Las salidas normal de la precipitación y temperatura durante agosto explicaron 99.8% y 95.3%, respectivamente, de la variación en la fecha del pico de la población de polillas capturadas.

The corn earworm, *Helicoverpa zea* (Boddie), is a periodic pest of soybeans in Maryland on the Delmarva peninsula. Herbert et al. (1991) reported that a third of the acreage in Virginia was treated annually with insecticides to control *H. zea*. The dynamics of *H. zea* are somewhat different in Maryland because of a lack of a large overwintering population like parts of Virginia and North Carolina. Although a small population does often overwinter in the most southern region of the peninsula, most of the population migrates into the area from more southern states (R. A. B., unpublished data). Field corn on the Delmarva peninsula provides a harborage for these immigrants which, coupled with continued migration of adults from further south and lack of parasitism, can result in the maintenance of large populations of *H. zea* that pose a threat to soybeans later in the summer (Zehnder et al. 1990).

The movement of *H. zea* into soybeans is governed by an array of factors, the most important of which is the relative condition of the corn (Stinner et al. 1982). Although corn is preferred over soybeans by ovipositing *H. zea* adults, senescing corn becomes less attractive compared with soybeans (Fitt 1989). If the corn stays green for a longer period, this may allow adjacent soybeans more time to mature and close their canopies,

thereby rendering them less susceptible to *H. zea* damage when moths finally shift their oviposition from mature corn. Corn earworm larvae were almost ten times more likely to exceed economic thresholds when soybean canopies were open as opposed to closed (Bradley et al. 1986). If soybeans are in a susceptible early reproductive stage like R2 (full bloom) when oviposition occurs, significant yield losses can result in a relatively short time (McWilliams 1983; Fehr & Caviness 1977; Kogan 1979).

A survey in Virginia, including the southern portion of the Delmarva peninsula, found significant parasitization of *H. zea* in soybeans (Zehnder et al. 1990). Our objective was to survey soybeans grown further north for parasite species attacking *H. zea* larvae in order to determine the rate of parasitism over time, along with other larval mortality factors like diseases. We sought to examine the relationship between moth captures in blacklight traps and larval populations in soybeans.

Materials and Methods

Soybean fields were sampled weekly over a three year period from 1995-1997 during the time when earworm adults typically shift ovipositing from corn to soybeans (Aug-Sep for the lower Eastern Shore of Maryland). Sampling was done with a standard insect sweep net to take 25 sweeps per sample with 10 samples per field. Each sample location was at least 50 paces from the previous one and areas were sampled only once. Care was taken to sample from the top of the soybean canopy down through the rest of the plants. Samplers walked along rows while sweeping alternately in both directions perpendicular to the row. The sizes of the fields ranged from 0.5 to 53 ha. This method is the recommended scouting protocol for soybeans in Delaware, Maryland, and Virginia with economic thresholds of three earworms per 25 sweeps in narrow row soybeans and five earworms in wide-row soybeans (Anonymous 1995a). The contents of the net were checked and earworms and other Lepidoptera were removed with a brush and placed immediately in 30-ml plastic cups containing standard insect diet (Southland Products, Inc., Lake Village, AR), one larva per cup. Larvae were held at 27°C and 15 h photophase until their parasitism status could be determined. The percentage of parasitism was calculated and corrected for larval mortality and the effect caused by the artificial removal of larvae from the potential population of hosts (Marston 1980). Any larvae that died without parasite emergence were dissected to check for immature parasites. Parasite identifications were conducted by the USDA-ARS Systematic Entomology Laboratory in Beltsville, MD. Voucher specimens of parasites were placed in the Maryland Department of Agriculture insect collection.

The number of adult moths captured in blacklight traps in 5-8 locations each year in the region was recorded and compared with larval captures. Blacklight traps were used because the state has operated a network of traps every year since 1973. These traps were placed in locations that were unique to each farm but consistent from year-to-year. Traps were 36.2 cm wide and 129.5 cm tall and used 15 watt blacklight bulbs powered by 115 V, 60 cycle AC current. Depending on the location, traps were suspended or placed on tripods that raised them 46-61 cm above the soil surface. Historic data from these traps allowed us to concentrate our sampling in areas that regularly experience high levels of *H. zea* adult captures. Temperature and precipitation data were collected from a network of weather stations in the region.

Multiple regression of the departures from normal in temperature and precipitation during the months of May through Sep., monthly averages of adult *H. zea* captures, and the Julian day for peak moth capture were used to construct a model with forward selection (SAS Institute 1990) to identify those variables which predicted the total number of larvae found in soybeans during a season. Monthly averages for adult captures were calculated by adding the average number of adults caught per night in a week, including any overlapping weeks between months, and dividing by the number of weeks. The peak moth date was the mid-week Julian day with the highest adult captures during the season. The averaging period to determine normals for temperature and precipitation was from 1961 to 1990 (Anonymous 1995b, 1996, 1997).

Results and Discussion

The number of *H. zea* larvae found in soybeans varied significantly among the sample years (Table 1). The average number of moths caught per month in black light traps had no predictive value for larval numbers in soybeans during the study period. However, there were consistent peaks in adult levels every year in late Aug. and early Sep. (Fig. 1). Our data agree with the findings of Herbert et al. (1991) regarding the influence of peak flights of moths and threats to the soybean acreage, namely, that earlier peaks increase risk. The weekly peak in 1995 was during the period Aug. 14-20, while in 1996 and 1997 both peaks occurred during Sep. 4-10 (Fig. 1). This average moth flight peak date explained 99.7% of the variation in larval captures in soybeans (df = 1,1; F = 404.34; P = 0.03).

The reasons for variability of the peaks in moth flights are unknown but probably are influenced directly by weather, and indirectly by the weather's effects on the corn crop. Direct effects might include prevailing winds and storm fronts

TABLE 1. INCIDENCE OF NON-PARASITISM MORTALITY FACTORS IN *H. zea* LARVAE COLLECTED FROM MARYLAND SOYBEANS, 1995-1997.

Collection dates	No. *H. zea*[1] collected	% *H. zea*[2] eclosed	% Dead from disease		% Unknown mortality
			N. rileyi	Virus	
15-Aug-1995	30	70.0	0.0	0.0	16.7
23-Aug-1995	162	50.0	0.0	0.0	12.3
30-Aug-1995	237	40.1	1.3	0.4	17.3
6-Sep-1995	154	32.5	0.0	0.0	13.6
12-Sep-1995	144	33.0	1.4	0.7	14.6
20-Sep-1995	65	7.7	4.6	0.0	12.3
All Dates 1995	762	32.9	1.0	0.3	15.2
13-Aug-1996	7	28.6	0.0	0.0	57.1
20-Aug-1996	9	33.3	0.0	0.0	33.3
4-Sep-1996	58	25.9	5.2	0.0	50.0
19-Sep-1996	61	1.6	34.4	9.8	31.1
All Dates 1996	135	15.6	17.8	4.4	40.7
27-Aug-1997	1	0.0	0.0	0.0	100.0
4-Sep-1997	4	0.0	0.0	0.0	25.0
9-Sep-1997	56	41.1	10.7	0.0	26.7
16-Sep-1997	73	35.6	9.6	0.0	23.3
25-Sep-1997	36	19.4	11.1	5.5	25.0
All Dates 1997	170	50.0	10.0	1.2	25.3

[1]All Dates row in this column refers to the sum total of *H. zea* larvae found that year.
[2]All Dates row in all remaining columns refers to the variable mean for that year.

which bring in migrants from the south or the temperature, which controls the rate of development of larvae in the corn. In our study, the average departures from normal precipitation and temperature in Aug. explained 99.8% and 95.3%, respectively, of the variation in the date of peak moth flights. Practical experience and other research has previously established a link between the weather, especially precipitation during the summer, and the condition of the corn which determines how long the crop is attractive to gravid females of *H. zea*. Hot, dry conditions likely increase the rate of larval development in corn, leading to an earlier moth peak while, at the same time, shortening the period when the corn remains attractive as an oviposition site. Usually, the aforementioned weather conditions will also retard the development of the soybean crop, slowing canopy closure and delaying maturities to stages more susceptible to damage from larval feeding. These conditions normally trigger alert warnings to growers from local organizations like the Cooperative Extension Service and state departments of agriculture.

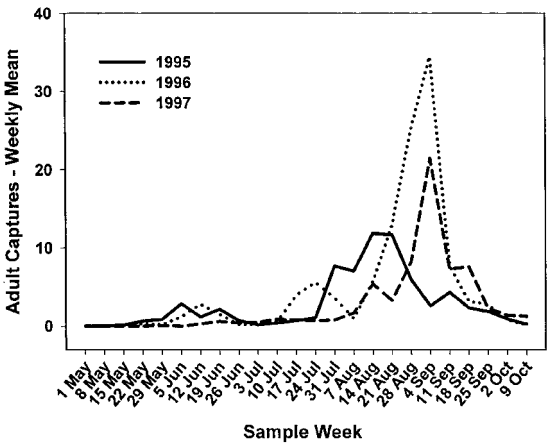

Fig. 1. Mean weekly capture of corn earworm moths from 1995-1997 in five to eight blacklight traps located in a three county area in the lower Eastern Shore region of Maryland.

In contrast, wetter, cooler conditions may act to maintain preferred oviposition sites for *H. zea* in the corn, by slowing development of the crop, thereby allowing the soybean crop to progress past the earlier, more vulnerable reproductive stages. Pressure in soybeans from *H. zea* larvae was highest in 1995 when the lower Eastern Shore areas experienced a severe drought (Fig. 2). In contrast, 1996 and 1997 experienced average to above average precipitation and *H. zea* populations were lower in soybeans (Fig. 2).

Over the period from 1995-1997, *Microplites croceipes* (Cresson) was the most frequently encountered parasite species attacking *H. zea* in soybeans (Fig. 3). Zehnder et al. (1990) and Her-

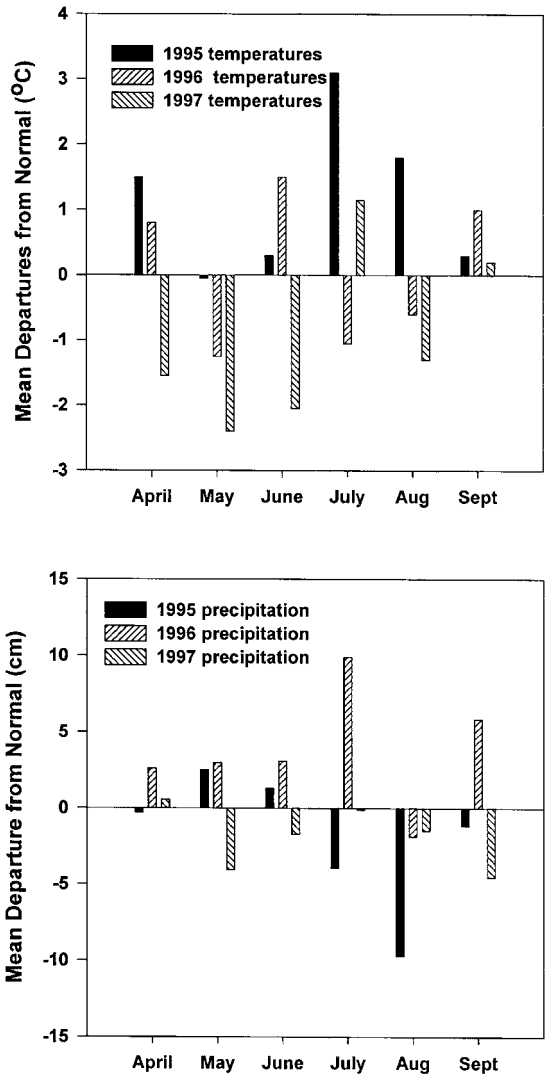

Fig. 2. Departures from mean temperature and precipitation during 1995-1997 from seven stations in the lower Eastern Shore region of Maryland.

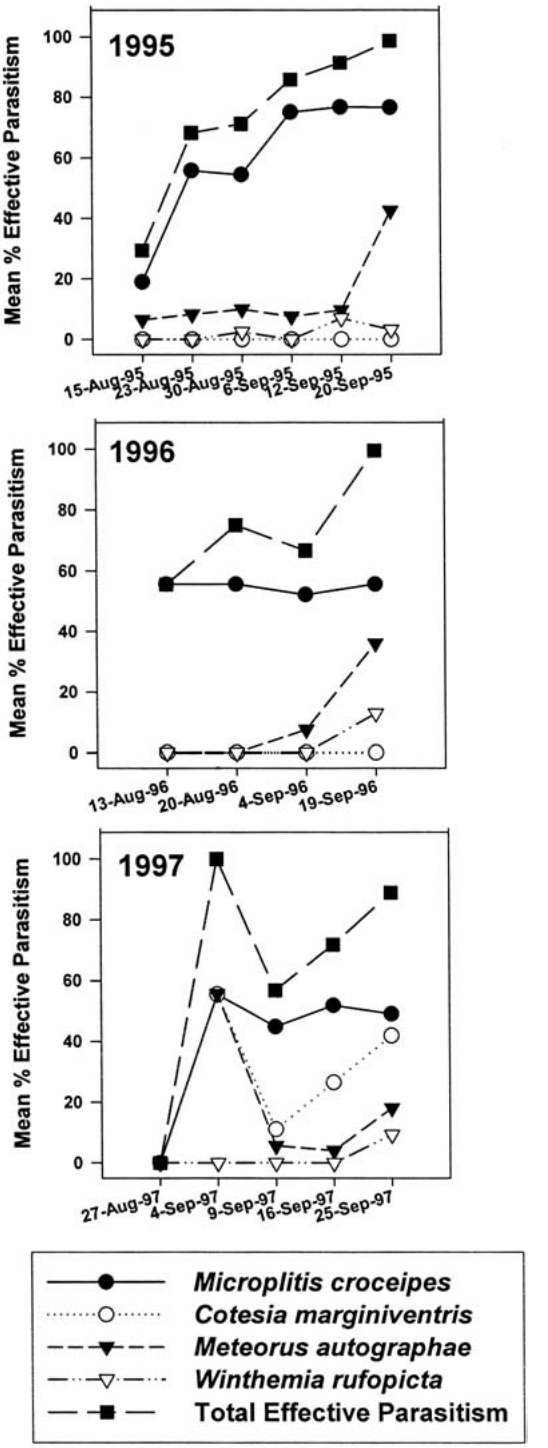

Fig. 3. Mean estimated effective parasitism of *H. zea* larvae collected from Maryland soybean fields from 1995-1997. Estimated effective parasitism (EEP) is calculated by first determining apparent parasitism (AP): AP = no. parasitized *H. zea*/no. parasitized *H. zea* + no. healthy *H. zea* (Marston 1980). EEP = AP + AP(1-AP) (Marston 1980).

bert et al. (1993) found similar results with this parasite. This native species is an important parasite of *H. zea* and other Heliothines (Stadelbacher et al. 1984; Bottrell et al. 1968; King et al. 1985). Other parasite species collected included *Cotesia marginiventris* (Cresson) (Hymenoptera: Braconidae), *Meteorus autographae* Muesbeck (Hymenoptera: Braconidae), and *Winthemia rufopicta* (Bigot) (Diptera: Tachinidae). In 1996, one *H. zea* larva was parasitized by *Glyptapanteles militaris* (Walsh) (Hymenoptera: Braconidae).

The weekly increase in parasitism was consistent across years with an average increase of 13.9%, 14.7%, and 22.2% each week during 1995, 1996, and 1997, respectively (Fig. 3). Only in 1995

were economic thresholds exceeded at some sites and growers prepared to apply insecticides. However, most of the cooperating farmers held off treating soybeans that year because the drought had degraded the value of their stands. These dry conditions resulted in few cases of disease among the collected larvae (Table 1). In contrast, the incidence of larvae with symptoms typical of infection by *Nomuraea rileye* (Farlow) and a virus increased in the next two years, which experienced wetter and cooler conditions than normal (Table 1).

Overall, this study demonstrated the utility of considering the departures from normal for precipitation, and perhaps temperature in Aug., in predicting risk to the soybean crop on the Delmarva peninsula from attack by *H. zea*. We do not suggest that this method take the place of cumulative experience or information from other sources, including sampling corn, nor does it provide an alternative for scouting soybeans and making control decisions. Rather, it supports existing conventional wisdom for managing this pest. However, further examination of the relationship between peak moth flights and weather conditions may provide growers with a quick and inexpensive method for predicting risk to their soybean crop and targeting their scouting efforts. Departure from normal data are readily available and can be quickly utilized to support decisions on the deployment of scouts.

This study also identified parasite species and quantified parasitism over the crucial period when soybeans are most vulnerable to *H. zea* attack. Although the ability of parasites to suppress *H. zea* populations in soybeans was not assessed, it is clear that a significant portion of the pest populations are consistently and heavily attacked by a suite of parasites, most notably *M. croceipes*. This species has been shown to be unaffected by differences in soybean cultivars such as leaf pubescence (Tillman & Lambert 1995). It also will search non-crop plants for hosts, such as *Geranium dissectum* L., a species with several close relatives that are common on the Delmarva peninsula (Kaas et al. 1993; Tatnall 1946). Hopper and King (1986) found that this parasite exhibited a linear functional response to host densities, a characteristic which should make it an important factor in suppressing *H. zea* populations, especially given the wide range of larval densities present in soybeans during this study. Judging by the rapid and regular disappearance of *H. zea* larvae from fields, parasites like *M. croceipes* may play a significant role in the population dynamics of this pest in Maryland soybeans.

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A NEW *FIDIOBIA* SPECIES (HYMENOPTERA: PLATYGASTRIDAE) REARED FROM EGGS OF *DIAPREPES DOUBLIERII* (COLEOPTERA: CURCULIONIDAE) FROM DOMINICA

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ABSTRACT

A new species of the genus *Fidiobia* reared from the eggs of *Diaprepes doublierii* collected in Dominica is described and illustrated. A key to the New World species of the genus *Fidiobia*, a host and distribution table of the 13 known *Fidiobia* species, and a summary of the efforts made to introduce natural enemies of *Diaprepes* species into Florida are provided.

Key Words: Platygastridae, *Fidiobia*, Curculionidae, *Diaprepes*, citrus weevil, biological control

RESUMEN

Se describe y se ilustra una nueva especie del género *Fidiobia* criada de los huevos de *Diaprepes doublierii* recolectados en Dominica. Se provee una clave de las especies de *Fidiobia* presentes en el Nuevo Mundo, y un cuadro del los hospederos y distribución de las 13 especies de *Fidiobia* conocidas. Se comentan los esfuerzos hechos para introducir enemigos naturales de especies de *Diaprepes* en el estado de Florida.

Translation provided by the authors.

In April of 2003, J. Peña, R. Duncan, C. McCoy, and J. Alegria, while conducting a survey of the egg parasitoids of *Diaprepes* species on citrus in Dominica, reared a new species of *Fidiobia* [Platygastridae] from eggs of *Diaprepes doublierii*, and transported it to the quarantine facility in Homestead, Florida for testing and subsequent introduction into Florida. After commenting on the species to Dr. Lubomir Masner, he suspected that it was the same undescribed species that he had collected in Dominica in 1994 and that J. Etienne had reared from *Diaprepes abbreviatus* in Guadeloupe in 1994. Dr. Masner sent specimens from these collections to the senior author, who determined that they were the same species that is described herein.

Ashmead (1894) erected the genus *Fidiobia* based upon specimens collected in Ohio (USA) and designated *Fidiobia flavipes* Ashmead as the type species. Including the new species described herein, the genus contains 13 species (Table 1); of these, 3 were described from the Nearctic, 4 from the Neotropical, 4 from the Palearctic and 2 from the Afrotropical region. Although no species of this genus have yet been described from the Oriental region, Masner and Huggert (1989) stated that the genus is worldwide in distribution with many undescribed species. With the exception of *Fidiobia flavipes*, which was reared from chrysomelid eggs, all of the other *Fidiobia* species for which the host records are known were reared from curculionid eggs. Readers are referred to Masner & Huggert (1989) for a key to the genera of Platygastridae which includes a diagnosis, discussion and illustrations for each platygastrid genus, and to Schauff (1987) for the key to the parasites of citrus weevils.

KEY TO NEW WORLD SPECIES OF *FIDIOBIA* (FEMALES)

1.	Notauli absent; head and thorax black, gaster lighter; legs brown except for yellow tarsi and apices of tibia	*citri* (Nixon)
1b.	Notauli present, either 2 thin, hairline streaks or 2 very broad, wedge-shaped cavities; body and leg color variable	2
2(1)	Notauli consisting of 2 thin, hairline streaks.	3
2b.	Notauli consisting of 2 very broad, wedge-shaped cavities	4
3(2b)	Gaster bright yellow; head and mesoscutum brown; legs yellow; F2 quadrate.	*dominica*, **n. sp.**

TABLE 1. HOST AND DISTRIBUTION OF *FIDIOBIA* SPECIES.

Species	Host	Distribution	Citation
Fidiobia asina (Loiacano)	Curculionidae: *Naupactus xanthographus*	Argentina	Loiacano (1982)
Fidiobia benjamini (Nixon)	Curculionidae: *Entypotrachelum micans*	Kenya	Nixon (1969)
Fidiobia bonariensis (Brethes)	unknown	Argentina	Brethes (1916)
Fidiobia citri (Nixon)	Curculionidae: *Diaprepes* spp.	Jamaica	Nixon (1969)
Fidiobia danielssoni Buhl	unknown	South Africa	Buhl (2001)
Fidiobia dominica Evans & Peña	Curculionidae: *Diaprepes doublerii, D. abbreviatus*	Dominica, Guadeloupe	Evans & Peña (current paper)
Fidiobia drakei (Oglobin)	unknown	USA: Iowa	Oglobin (1944)
Fidiobia flavipes Ashmead	Chrysomelidae: *Fidia viticida*	USA: Ohio, New York	Ashmead (1894) Fouts (1924) Ellis (1973)
Fidiobia hofferi Kozlov	unknown	Czech Republic, Norway, Sweden	Kozlov (1978)
Fidiobia polita Buhl	unknown	Sweden	Buhl (1999)
Fidiobia pronotata Szabo	unknown	Hungary, Moldavia	Szabo (1958)
Fidiobia rugosifrons Crawford	Curculionidae: *Hypera postica*	Canada, USA: Indiana, Pennsylvania; Panama; Central Asia, Sweden, Norway	Crawford (1916) Buhl (1998, 1999, 2002)
Fidiobia syngorgum (Keiffer)	unknown	Norway	Buhl (1999)

3b. Body dark brown to black with metasoma gradually becoming lighter towards apex; coxae, femora and central portion of tibia II and III brown; F2 transverse. . . . . *asina* (Loiacano)

4(2b) Antennae completely yellow; body brown . . . . . *flavipes* Ashmead

4b. Antennae yellow with dark brown club; body black 5

5(4b). F1 short, rectangular, about as long as F2; head and mesoscutum apparently without fine thimble-like sculpture . . . . . *drakei* (Oglobin)

5b. F1 long, trapezoidal, about 1.5× as long as F2; head and mesoscutum with fine, thimble-like sculptures . . . . . *rugosifrons* (Crawford)

**Fidiobia bonariensis* (Brethes) was not included in key because the description of the species lacked sufficient detail to distinguish it from other species; however based on the coloration and the shape the antennal segments, we suspect that it is very similar to, if not conspecific with, *F. rugosifrons* (Crawford).

Fidiobia dominica Evans and Peña, **n. sp.**

Female (Figs. 1, 2, 4). Length: 1.4-1.45 mm.

Diagnosis

Fidiobia dominica can be distinguished from all of the other *Fidiobia* species by having the gaster entirely yellow and the notauli represented by thin, hairline streaks. It is most similar to *F. asina* in that both species have the notauli represented by a thin, hairline streak, but can be distinguished from the latter species by having the gaster and legs bright yellow and the F2 antennal segment quadrate; whereas in *F. asina*, the body is dark brown to black with the gaster becoming lighter towards the apex; the coxae, femora and central portion of tibia II and III are brown, and F2 is transverse.

Description

Color (Fig. 1). Head and thorax dark brown to black; gaster, legs and antennal scape, pedicel and funicle yellow; antennal club dark brown; wings slightly infuscate.

Head (Fig. 1). About as wide as thorax, subellipsoidal with rounded vertex; eyes glabrous with scattered minute setae; malar sulcus absent; cheeks smooth; mandibles short, bidentate; palpal formula 1-1; tongue (galea) with 1 central peg and 2 pairs of marginal pegs.

Antennae (Fig. 2). With 4 funicle segments, club 3-segmented and compact. Length, width and length/width measurements for antennal segments as given in Table 2.

Thorax (Fig. 1). Midlobe distinctly wider than long with elongate reticulations along the anterior margin and sublaterally with smooth central area and lateral margins, and 34-36 short, thin setae; notauli thin, hairstreak-like extending from the posterior margin to about 3/4 to the anterior margin; scutellum smooth with placoid sensillae widely separated (42.5) and with 10 slender setae along the posterior margin; metanotum smooth, slightly shorter than half the length of the scutellum; propodeum long with numerous long hairs.

Forewing (Fig. 4). Elongate and slender 2.73 as long as wide, submarginal vein short (87.5) about 0.24× as long as the forewing, stigmal vein with 3 sensoriae and a single long seta, marginal fringe 0.15× as long as maximum width of forewing.

Legs (Fig. 1). Middle leg tibia (200) and basitarsus (67.6), tibial spur (25).

Gaster (Fig. 1). Tergite I wider than long, 0.88 times as long as gastral tergites II-VI, smooth except for elongate reticulations along the submarginal area extending from the anterior margin to about 3/4 to the posterior base, with long hairs along the anterior margin and in a pair of elliptical-shaped areas along the submarginal area, tergites II-IV reticulate centrally and smooth laterally, tergites V-VI smooth; ovipositor arising at base of gaster and extending to the posterior apex, not exserted.

Male (Figs. 3, 5). Similar to female in color and structure with segments of antennal club more separated (Fig. 3) with measurements as given in Table 2 and genitalia as shown in Figure 5.

Specimens Examined and Deposition

Holotype female: Dominica: Parish, Cuba, 26.vi.2003, R. Duncan and J. Alegria, ex. egg mass of *Diaprepes doublierii* on *Citrus* sp., deposited in the U.S. National Museum of Natural History (USNM); Paratypes—Dominica: Grand Bay, 28.iv.2003, J. Peña and C. McCoy, ex. egg mass of *Diaprepes doublierii* on *Citrus* sp.; Dominica: Syndicate, 28.iv.2003, J. Peña and C. McCoy, ex. egg mass of *Diaprepes doublierii* on *Citrus* sp.; 2 females, Dominica, St. Peters Parish, Morne, Diabloton, 700-900 m 26.xi.1004, L. Masner, virgin forest; 7 females and 9 males, Guadeloupe, Bouillante Pigeon, 24.vi.1994, J. Etienne, ex. *Diaprepes abbreviatus* egg mass on *Citrus* sp., deposited in the Florida Collection of Arthropods, Gainesville, Florida and in the Canadian National Collection, Ottawa, Canada.

Etymology

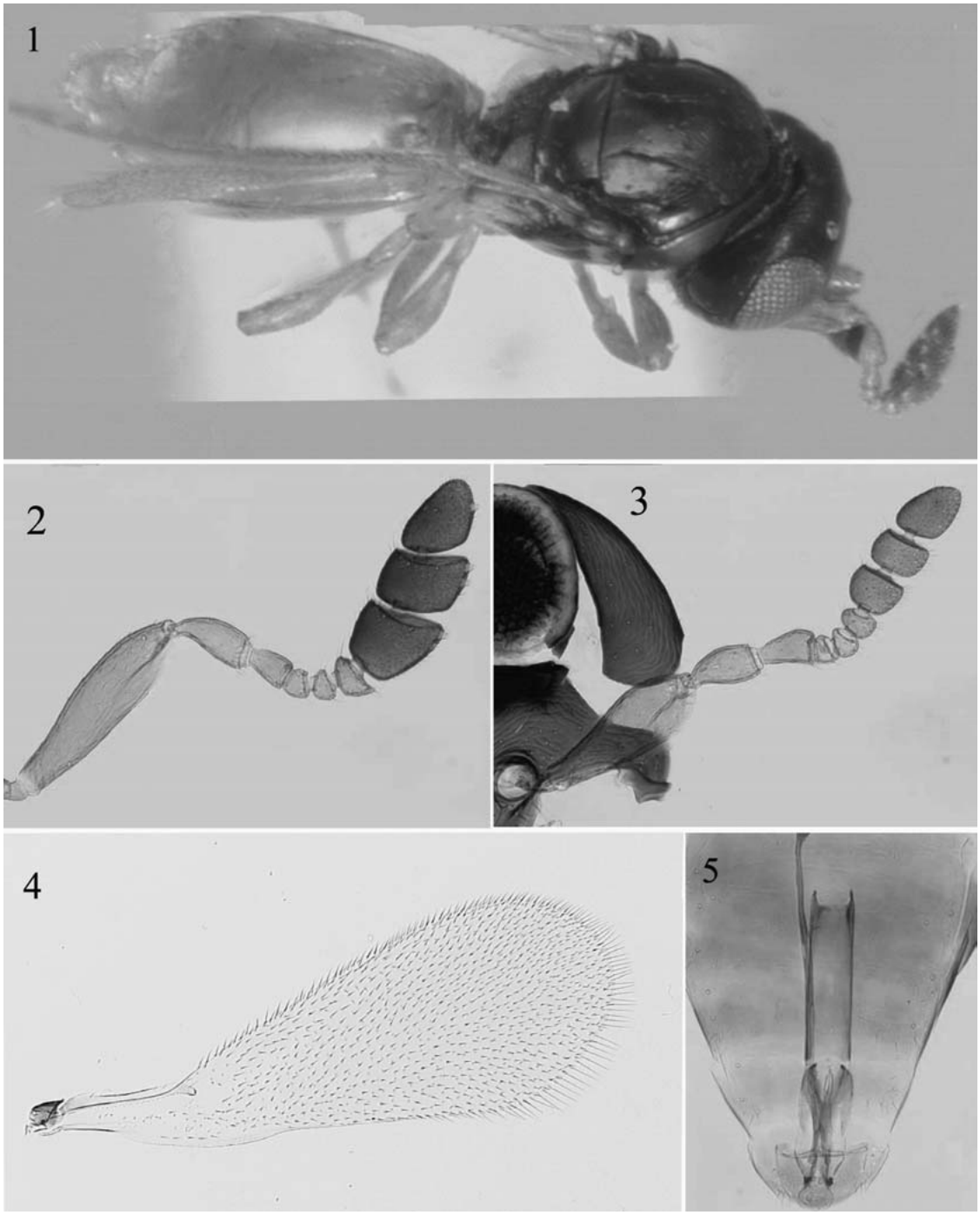
This species is named for the country where it was discovered.

Discussion

Diaprepes abbreviatus (Linnaeus) was introduced into Florida in 1964 (Woodruff 1964) and since has become a serious pest of citrus throughout much of the central and southern Florida. A biological control program was initiated to develop and implement strategies to manage the root weevil, *D. abbreviatus* in response to the spread of the weevil in Florida and latest infestations in Texas and California (Knapp 1985; Woodruff 1968; McCoy & Simpson 1994; Mannion et al. 2003; Godfrey et al. 2002). Because of a lack of

Table 2. Measurements (μM) of holotype female and allotype male *Fidiobia dominica*.

Female (holotype)				Male (Allotype)			
segment	length	width	length/width	segment	length	width	length/width
Scape	152.5	42.5	3.59	Scape	125.0	47.5	2.63
Pedicel	62.5	22.5	2.78	Pedicel	52.5	27.5	1.91
F1	30.0	20.0	1.50	F1	43.7	25.0	1.75
F2	17.5	22.5	0.78	F2	17.5	20.0	0.88
F3	15.0	22.5	0.67	F3	17.5	22.5	0.78
F4	17.5	30.0	0.58	F4	17.5	25.0	0.70
C1	60.0	57.5	1.04	C1	30.0	37.5	0.80
C2	37.5	57.5	0.65	C2	25.0	37.5	0.67
C3	50.0	47.5	1.05	C3	42.5	35.0	1.24
Forewing	362.5	132.5	2.73				
Scutellum	62.5	170.0	0.36				
Metanotum	30.0	200.0	0.15				
Propodeum	80.0	237.5	0.37				
Gaster T1	265.0	315.0	0.84				
Gaster T2-T6	300.0	315.0	0.95				



Figs. 1-5. *Fidiobia dominica*. 1) female habitus, 2) female antenna, 3) male antenna, 4) female forewing, 5) male genitalia.

native egg parasitoids found attacking this weevil in citrus orchards in Florida (Hall et al. 2001) and past failures of classical biological control of this weevil (Beavers et al. 1980), renewed efforts were initiated to introduce, release, and evaluate candidate egg parasitoids from the Caribbean Region into Florida (Peña et al. 1998; Peña & Amalin 2000; Hall et al. 2002). For instance, *Brachyufens*

osborni (Dozier), a trichogrammatid wasp described from specimens reared from *Diaprepes abbreviatus* in Puerto Rico was introduced into Florida but has not been recovered from *D. abbreviatus* in Florida, although it has been reared from eggs of *Pachnaeus opalus* on citrus.

Foreign exploration for egg parasites of *Diaprepres* and other genera of citrus weevils has been conducted in several Caribbean and Central American countries (Peña et al. 2000; Hall et al. 2002) to introduce them into Florida for classical biological control of *Diaprepes abbreviatus*. *Quadrastichus haitiensis* (Gahan) (Hymenoptera: Eulophidae), previously reported under the name *Tetrastichus haitiensis* (Schauff 1987), was released during the 1970s in Apopka (central Florida) and in West Palm Beach (southeastern Florida) (Beavers & Selhime 1975), but failed to establish (Beavers & Selhime 1975). In 1998, Hall, Nguyen and Stansly obtained the parasitoid from Puerto Rico and attempted to introduce it into Florida again. In 2002, subsequent releases of the parasitoid were made in citrus and ornamental fields in Florida. *Quadrastichus haitiensis* (Gahan) is established in the southern part of the state (Miami-Dade County), but has failed to establish in mid, central, and southwest Florida (Peña et al., unpublished data).

Ceratogramma etiennei Delvare (Hymenoptera: Trichogrammatidae), is a highly specific egg parasitoid of *D. abbreviatus* from Guadeloupe (Etienne et al. 1990). This species was introduced into Florida from Guadeloupe in 1997 (Peña et al. 1998) and released during 1998 in citrus, ornamental fields and natural habitats infested with the *Diaprepes* root weevil but failed to establish (Peña et al. unpublished data).

A third parasitoid, *Aprostocetus gala* (Walker) (Hymenoptera: Eulophidae), also known as *Tetrastichus gala* Walker and *Aprostocetus vaquitarum* Wolcott, was found in high numbers parasitizing *Diaprepes* root weevil eggs in the Dominican Republic during 2000 (Peña & McCoy, pers. obs.) and was subsequently released during 2001 at several sites across Florida. Again, while the parasitoid is successfully established in ornamental and citrus groves in Miami-Dade County, its recovery continues to be erratic in other parts of the state (Peña et al. unpublished data).

Fidiobia dominica was found parasitizing 11% of collected eggs (n = 35 eggs) in the survey for egg parasitoids of *Diaprepes* spp. conducted in Dominica. In quarantine, when egg masses of *Diaprepes abbreviatus* are exposed to the parasitoid, percent parasitism ranged from 26-65%, depending on the substrate on which the host eggs are laid, e.g., host plant versus wax paper or concealed eggs versus non-concealed eggs (Duncan & Peña, unpubl.). Under quarantine conditions, 25°C, 75-80% Rh., 12:12 L:D h photoperiod, *Fidiobia dominica* deposits eggs singly in eggs of the *Diaprepes* weevil. The eggs hatch in approximately 1 d and the free-living first instar feeds directly upon the fluid of the weevil egg. Parasitized eggs are a dark gold color. Parasitoids will emerge from parasitized eggs within approximately 10-12 days. If fed honey and water, *Fidiobia dominica* adults live a range of 4 to 8 days. A parasitized egg mass can produce 7 to 19 parasitoids depending on the substrate where the weevil eggs are laid. For instance, a higher parasitoid emergence is observed when eggs are laid on leaves compared to artificial substrates, such as wax paper (Duncan & Peña, unpubl.). *Fidiobia dominica* has been successfully reared for several generations on *Diaprepes abbreviatus* eggs in quarantine; when approved, it will be released at various sites in Florida.

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BIOLOGY OF *GONATOCERUS TUBERCULIFEMUR* (HYMENOPTERA: MYMARIDAE), AN EGG PARASITOID OF THE SHARPSHOOTER, *TAPAJOSA RUBROMARGINATA* (HEMIPTERA: CICADELLIDAE)

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ABSTRACT

Biological traits of a prospective candidate for biological control of the glassy-winged sharpshooter (GWSS), *Homalodisca coagulata* (Say) (Hemiptera: Cicadellidae), in the United States are herein reported. The mymarid wasp, *Gonatocerus tuberculifemur* (Ogloblin), is an egg-parasitoid native to Argentina and its first known host is *Tapajosa rubromarginata* (Signoret), a species related to GWSS. Laboratory studies were made in Tucumán and Buenos Aires Provinces, Argentina. Seven generations were maintained in the laboratory, and only one adult emerged per host egg. The average parasitism rate was 71.6% of total eggs. Although eggs of all ages (4 to 190 h old) were parasitized, wasps did not emerge from eggs over 96 h old. The percentage of wasp emergence was 66.5% from eggs between 4 and 72 h old. Over the seven generations that *G. tuberculifemur* was reared, the parasitism rate ranged between 55-84%. This percentage of emergence increased as the parasitoid generations progressed. The duration of development from oviposition to adult emergence of *G. tuberculifemur* was 12.6 ± 1.8 days (range 11.4-13.0) at 22.5-27.5°C and 70-80% RH. The duration of development was significantly affected by sex and temperature. Males developed faster than females (12.2 vs. 12.8, respectively).The sex ratio was not significantly different from 1:1. Average adult longevity was 6.73 ± 3.93 days fed on honey. Male and female longevity was not significantly different. Oviposition and mating behavior are described.

Key Words: glassy-winged sharpshooter, *Homalodisca coagulata*, biological control, bionomics, *Gonatocerus*, Mymaridae, egg parasitoid

RESUMEN

Se informan los resultados del estudio de las características biológicas de la avispa Mymaridae *Gonatocerus tuberculifemur* (Ogloblin), un parasitoide de huevos, nativo de Argentina cuyo primer hospedador conocido es el sharpshooter *Tapajosa rubromarginata* (Signoret). Esta avispa es un candidato potencial para el control biológico de la chicharrita de alas cristalinas, *Homodalisca coagulata* (Say) (Hemiptera: Cicadellidae) en los Estados Unidos de Norteamérica. Esta especie fue estudiada bajo condiciones de laboratorio en las Provincias de Tucumán y Buenos Aires, Argentina. Siete generaciones fueron obtenidas, y solo un adulto emergió de cada huevo parasitado. El porcentaje promedio de huevos parasitados fue de 71.6%. A pesar que huevos de todas las edades testeadas (4-190 horas) fueron atacados por hembras de *G. tuberculifemur*, no emergieron avispas de huevos con mas de 96 horas de edad. El porcentaje de emergencia de avispas fue 64.1%. Durante las siete generaciones criadas el porcentaje de parasitsmo osciló entre 55 y 84% del total de huevos, este porcentaje se incrementó con el avance de las generaciones. El tiempo necesario para completar el desarrollo de *G. tuberculifemur* (desde huevo hasta adulto) fue de 12.6 ± 1.8 días (rango 11.4-13.0) a 22.5-27.5°C y 70-80% HR, y fue significativamente afectado por la temperatura y el sexo. Los machos necesitaron menos tiempo para desarrollar (12.2 días) que las hembras (12.8 días). La proporción de sexos no mostró diferencias significativas. La longevidad de los adultos alimentados con miel fue de 6.73 ± 3.93 días, y no mostró diferencias significativas entre los sexos. Se describe el comportamiento de oviposición y cópula.

Translation provided by the authors.

Most of the Auchenorrhyncha (Hemiptera) which are economically important to agriculture are vectors of plant diseases such as viruses and bacteria. The glassy-winged sharpshooter (GWSS), *Homalodisca coagulata* Say (Hemiptera: Cicadellidae: Proconiini), has recently become a major pest in California, primarily as a vector of *Xylella fastidiosa* Wells et al., which causes Pierce's disease in grape vines and also infects other crops. In California, wine and table grape producers are under threat due to the action of the GWSS in vectoring this pathogen. Biological control is an important component in the management of the GWSS (Morgan et al. 2000; Jones 2001). In general, Cicadellidae are not infected by pathogenic viruses, bacteria, and protozooa, however, they are infected by pathogenic fungi (Soper 1985). Waloff & Thompson (1980) and Denno & Roderick (1990) found that mortality produced by egg parasitoids was a "key factor" in Cicadellidae species. These parasitoids are one of the few taxa playing an important role in limiting leafhopper populations (Döbel & Denno 1993). Mymarid wasps are the best-known egg parasitoids of leafhoppers, and representatives of the family have been successfully utilized in several instances for the control of crop pests (Huber 1986; Meyerdirk & Moratorio 1987).

The egg parasitoid, *Gonatocerus tuberculifemur* (Ogloblin), was found in several surveys for egg parasitoids of Proconiini sharpshooters in Argentina during 2000-2004. Until 1986, 252 species of *Gonatocerus* were known, with 60 described from the Neotropics (Huber 1986). Of the 30 species described from Argentina, only three have known host records (De Santis 1957, 1979).

Few studies have been published on the bionomics of *Gonatocerus* (Miura 1979, 1990; Sahad 1982). There is no information on the bionomics of *G. tuberculifemur*. We studied aspects of its biology (egg-laying behavior, egg viability, duration of developmental stages, sex ratio, and longevity) reared under laboratory conditions on its natural host, *Tapajosa rubromarginata* (Signoret).

Materials and Methods

The studies were carried out in Planta Piloto de Procesos Industriales Microbiológicos, CONICET, San Miguel de Tucumán, Tucumán Province, and at the USDA-ARS, South American Biological Control Laboratory, Hurlingham, Buenos Aires Province. Laboratory studies were conducted to asses the effects of temperature on development time, progeny sex ratio, adult longevity, oviposition, and mating behavior.

Parasitoid Culture

A culture of *G. tuberculifemur* was initiated in the laboratory by collecting 20 egg masses of *T. rubromarginata* on Johnson grass, *Sorghum halepense* (L.), in an open field in San Miguel de Tucumán, Tucumán Province, in September 2002. Additional collections were made when necessary. The female *Tapajosa rubromarginata* lays her eggs in parallel rows in groups of 3 to 32 eggs per mass (n = 68, mean = 15.0; SD = 6.0) just under the epidermis layer (E. G. V. unpublished data).

In the laboratory, field-collected (by sweeping) females of *T. rubromarginata* placed in polyethylen-terephtalathe (PET) cylindrical cages (35 cm high × 18 cm diam.) on maize leaves were used to obtain host eggs. Potted maize plants (pot of 6.3 dm^3) in the vegetative stage (four to eight leaves) were checked daily for eggs. When egg masses were detected, the sharpshooters and the PET cages were removed, and the corn leaf was introduced into a 20-cm high × 2-cm diam glass tube with 1-3 mated *G. tuberculifemur* females (24-48 h old) for 24 h. Each glass tube top was fitted with a cotton plug, which was moistened with water and honey as needed. After five days, the parasitized egg masses were removed from the leaf and transferred to a Petri dish with wet tissue paper and covered with clear plastic food wrap to prevent desiccation, and to keep wasps from escaping. Parasitized egg masses were checked daily to ensure leaf quality until the emergence of the adult wasps.

Not all exposed eggs were parasitized, so to estimate percent parasitism, host eggs that changed to brownish or reddish after five to seven days were considered "parasitized", while those developing eyespots were considered "unparasitized". The number of leafhopper nymphs and wasps that emerged from the exposed eggs were counted daily. Host age acceptability was studied at six different ages: 4, 24, 48, 72, 96, and 190 h.

The total time required for the development from egg to adult emergence, and progeny sex ratios were measured at 4 temperatures: 22.5°C ± 1.3, 24.5°C ± 1.3, 26.0°C ± 1.3, and 27.5°C ± 1.3 in 875 individuals (457 males, 504 females) from 102 attacked egg masses. Differences in the duration of the development between male and females were analyzed by a two-factor ANOVA.

Adult longevity was estimated based on the observation of 114 individuals (56 females and 58 males). Adults were kept individually in vials (7 cm length × 1 cm diameter) without host material, but with honey for food. The experiment was carried out under room temperature (22.9°C ± 8°C) at 70-80% RH with ambient natural light providing, a summer photoperiod of approximately 15 L: 9 D. Differences between male and females longevity were analyzed by a t test. The effect of temperature on sex ratio was analyzed by one-way ANOVA.

Voucher specimens were deposited in the entomological collections of M. Lillo Institute (Tucumán, Argentina) and the University of California at Riverside (Riverside, California, USA).

Results

Gonatocerus tuberculifemur is solitary, producing only one adult per host egg. During the study, 102 out of 142 egg masses exposed were attacked, producing 961 wasps from 1500 parasitized eggs out of 2095 exposed.

The average parasitism rate for all eggs was 71.6%; however, it differed according to egg age (Table 1). Although eggs of all ages were parasitized, wasps did not emerge from eggs aged 96-190 h old. The percentage of wasp emergence was 64.1% (from eggs between 4 and 72 h old). The maximum percentage of wasp emergence was obtained from 48-h-old eggs (71.5%). The average of host nymph emergence for all egg ages was 12.2%; increasing to 65.7% in eggs aged 190 h. No noticeable effect of host egg age was observed on the sex ratio, longevity, or on development time. Most of the *G. tuberculifemur* adults emerged between 10:00 and 15:00 h. A similar observation was reported by Sahad (1982) studying *Gonatocerus* sp. attacking *Nephotettix cincticeps* Uhler in Japan.

Over seven generations (142 masses, 2095 eggs exposed), the parasitism rate ranged between 55-84%, and the emergence of wasps from 45 to 87% (Table 2). The emergence rate increased over generations, from 58.5% during the first generation, to 86.3% for the seventh generation.

The immature stages of the parasitoid produced changes in the host egg. In the first three days it was not possible to identify the parasitized eggs through changes in coloration, except for tiny dark oviposition marks in the leaf cuticle and/or chorion. Host eggs containing parasitoid larvae (2-5-days-old) had distinctive light brown coloration. After 4-7 days, the whole egg became orange or red. When the parasitoids reached the pupal stage (6-12 days), it turned to dark brown or black.

The duration of development from oviposition to adult emergence of *G. tuberculifemur* was 12.6 ± 1.8 days (range 11.4-13.0). The duration of development of *G. tuberculifemur* was influenced by temperature (F = 32.130; df = 3, 861; P = 1.09E-19), by sex (F = 21.082; df = 1, 861; P = 5.05E-06), and by the interaction between temperature and sex (F = 2,888; df = 3, 861; P = 0.03). Overall, males developed faster than females (Table 3). At 22.5 and 24.5°C, males did not show differences in duration of development (Table 3). On the other hand, duration of development of females was not different at 26 and 27.5°C. The sex ratio was slightly female biased at 1.1: 1 (n = 504 females, 457 males), without being different (F = 2.308; df = 3, 98; P = 0.0812).

Adult longevity was 6.73 ± 3.93 days, showing high variability. Few individuals were able to survive more than 15 days. There was no difference in longevity by sex (Fig. 1) (t = -0.464; df = 1; P = 0.32). About 50% of the adults died on the 7th day.

Parasitoid mating behavior was observed as follows. Immediately upon emergence, males rushed for the females and mating occurred as soon as they managed to reach the females and position themselves appropriately. It was common to observe as many as 2-4 males around one female. Each mating lasted 4-10 seconds. One male was observed trying to mate with a female while she was emerging.

No premating or preovipositional period was observed; the oviposition of *G. tuberculifemur* began immediately after adult emergence. They searched rapidly over the leaves, tapping the surface constantly with the tips of the antennae on a host egg mass. It was not determined whether host location was by random search or by directional cues. However, females found the eggs very quickly. Any time that a female was caged with a plant containing an egg mass, the female located the egg mass and began oviposition within 30 seconds; this behavior was observed at least 30 times when females were caged. The process of oviposition was initiated after the host was examined; the female positioned the tip of the abdomen on the host egg, the ovipositor was then extruded and inserted through the leaf cuticle. As a general behavior, once oviposition began, a female continued laying eggs on the remaining eggs in the mass. The main cause of oviposition interference was the arrival of another female at the egg mass; as a consequence, one of them abandoned the egg

Table 1. Effect of *Tapajosa rubromarginata* egg age on percent parasitism by *Gonatocerus tuberculifemur*.

Egg age (hours)	No eggs exposed (no. masses)	No. parasitized eggs (%)	No. emerged wasps (%)	No. emerged nymphs (%)
4	232 (19)	121 (52.7)	76 (62.8)	51 (22.0)
24	1222 (74)	863 (70.6)	578 (67.0)	180 (14.7)
48	394 (29)	340 (86.3)	243 (71.5)	2 (0.5)
72	158 (15)	122 (77.2)	64 (52.5)	0 (0.0)
96	54 (3)	51 (94.4)	0 (0.0)	0 (0.0)
190	35 (2)	3 (8.6)	0 (0.0)	23 (65.7)
Total	2095 (142)	1500 (71.6)	961 (64.1)	256 (12.2)

TABLE 2. NUMBER OF PARASITIZED EGGS AND WASP EMERGENCE OF *GONATOCERUS TUBERCULIFEMUR* OVER SEVEN GENERATIONS REARED ON *TAPAJOSA RUBROMARGINATA* UNDER LABORATORY CONDITIONS.

Generation	No. egg masses	No. eggs exposed	No. eggs parasitized (%)	No. wasps emerged (%)	No. nymphs emerged(%)
I	30	447	359 (80.3)	210 (58.5)	36 (8.1)
II	28	331	279 (84.3)	137 (49.1)	15 (4.5)
III	19	338	186 (55.0)	84 (45.2)	42 (12.4)
IV	19	241	183 (75.9)	126 (68.8)	4 (1.7)
V	10	151	104 (68.9)	90 (86.5)	27 (17.9)
VI	21	238	178 (74.8)	132 (74.2)	40 (16.8)
VII	15	349	211 (60.5)	182 (86.3)	92 (26.4)

mass to continue looking for other egg masses in the container. Superparasitism was observed in the laboratory when 1 or 2 females were placed in a container. In both cases, only one wasp emerged from each egg.

DISCUSSION

Gonatocerus tuberculifemur can be considered as proovigenic, due to its ability to deposit eggs immediately after emergence (Flanders 1950). This characteristic is shared with *G. cincticipitis* Sahad (Miura 1990), and other members of the Mymaridae (Clausen 1940). *Tapajosa rubromarginata* is the first host recorded for this parasitoid.

The parasitism rate obtained in the laboratory (71.6%) was much higher than that obtained for *Gonatocerus* sp. (48.7%) parasitizing *N. cincticeps* (Miura 1979). The percentage of parasitized eggs that produced wasps (63.4%) was lower compared to that obtained by Virla (2001) on *Anagrus breviphragma* (80.5%), possibly due to differences in the rearing methods used. In the present study, egg masses were removed from the plant prior to parasitoid emergence, whereas in Virla's study, the host eggs were allowed to remain on the plant until wasp emergence. Rotting or desiccation of the eggs' host plant substrate leads to offspring death (Sahad 1984). Better humidity control may lead to higher wasp emergence rates.

Mymaridae show two behaviors regarding host suitability: true egg parasitoids that can attack and develop on newly laid eggs (before embryo development), and those that attack eggs in all their developmental stages. However, when eggs with advanced embryos are attacked, only some species are able to develop to the adult stage (Clausen 1940; Waloff 1979; Chantarasa-ard & Hirayima 1984). *Gonatocerus tuberculifemur* females were able to parasitize eggs of all development stages, but wasps did not emerge when eggs older than 96 h were attacked. Eggs older than 72 h were unsuitable for laboratory rearing and for field collection of parasitoids as "sentinel" eggs. Although parasitoid offspring cannot develop to the adult stage in eggs with well-developed embryos, the host egg is nevertheless killed. Further research is needed to establish whether *G. tuberculifemur* can attack eggs with well-developed embryos in the field.

The duration of development was significantly different between males and females. For *Gonatocerus* sp., Miura (1979) found no differences between males and females. Virla (2001) reported that sex affected development rate in *Anagrus* sp., but Meyerdirk & Moratorio 1987 found no differences in their studies with another *Anagrus* sp.

The observed ovipositional and mating behaviors, and the results for sex ratio and adult longevity obtained in this study, were similar to those

TABLE 3. EFFECT OF THE TEMPERATURE AND SEX ON DURATION OF DEVELOPMENT OF *GONATOCERUS TUBERCULIFEMUR* UNDER LABORATORY CONDITIONS.

	Males			Females		
Temperature (°C)[1]	*n*	Mean (days)	SD	*n*	Mean (days)	SD
22.5	130	12.7	2.1	105	13.7	0.8
24.5	194	12.7	1.7	212	13.3	1.6
26.0	76	12.0	1.6	118	12.0	1.9
27.5	57	11.5	1.3	69	12.0	2.0
Overall mean	457	12.2	1.8	504	12.8	1.8

[1]The duration of the development was influenced by temperature (F = 32.130; df = 3, 861; P = 1.09E-19), by sex (F = 21.082; df = 1, 861; P = 5.05E-06), and by the interaction between temperature and sex (F = 2,888; df = 3, 861; P = 0.03) (Two-way ANOVA).

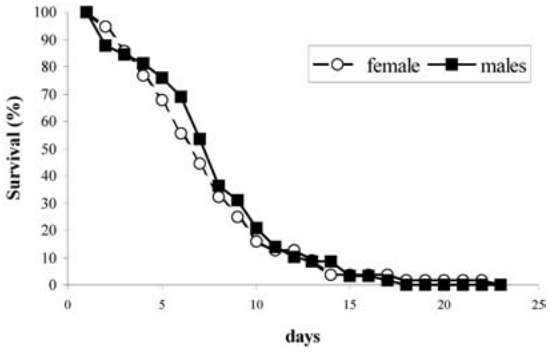

Fig. 1 Survival of males and females of *Gonatocerus tuberculifemur*.

reported for other *Gonatocerus* and *Anagrus* species (MacGill 1934; Clausen 1940; Miura 1979; Waloff 1979; Chantarasa-ard et al. 1984; Sahad 1982, 1984; Meyerdirk & Moratorio 1987).

A culture of *G. tuberculifemur* has been successfully maintained since March 2001 at the USDA-APHIS Mission Texas quarantine laboratory with eggs of a factitious host, *H. coagulata*, where the biology on this host egg is being studied. In the USDA-ARS SABCL and in the USDA-APHIS Mission laboratories the parasitoid host range is under study.

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COMPARISON OF BEETLE DIVERSITY AND INCIDENCE OF PARASITISM IN DIABROTICINA (COLEOPTERA: CHRYSOMELIDAE) SPECIES COLLECTED ON CUCURBITS

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ABSTRACT

Diabroticina (Chrysomelidae: Galerucinae: Luperini) beetles were sampled under field conditions on two host plants of the family Cucurbitaceae, *Cucurbita okeechobeensis* ssp. *martinezii* L. Bailey (bitter, wild cucurbit) and *C. moschata* (Lam.) Poiret (non bitter, cultivated cucurbit). Seventeen species of Diabroticina were collected. *Acalymma blomorum* Munroe & Smith was the most abundant species on both host plants. The only parasitoid found was *Celatoria compressa* Wulp (Diptera: Tachinidae). This parasitoid attacked more beetle species on the cultivated cucurbit (65%) than on the bitter cucurbit (20%). However, the percentages of parasitism observed in all species were low (0.4% to 12.5%). These data suggest that host plant species might have an effect on parasitism.

Key Words: *Acalymma*, *Celatoria compressa*, *Cucurbita okeechobeensis* ssp. *martinezii*, *Cucurbita moschata*, host plant association, Diabroticina beetles

RESUMEN

Diecisiete especies de Diabroticina (Chrysomelidae: Galerucinae: Luperini) fueron colectadas en dos plantas hospederas de la familia Cucurbitaceae, *Cucurbita okeechobeensis* ssp. *martinezii* L. Bailey (amarga, silvestre) y *C. moschata* (Lam.) Poiret (no amarga, cultivada). *Acalymma blomorum* Munroe & Smith fue la especie más abundante en ambas hospederas. Se obtuvo únicamente el parasitoide *Celatoria compressa* Wulp (Diptera: Tachinidae) sobre las poblaciones de Diabroticina. Este parasitoide atacó mayor número de especies de escarabajos en la calabaza cultivada (65%) que en la calabaza amarga (20%). Los porcentajes de parasitismo observados se consideraron bajos (0.4% a 12.5%). Los datos sugieren que las plantas hospederas pudieron haber tenido un efecto sobre el parasitoide.

Translation provided by authors.

Diabroticina (Chrysomelidae: Galerucinae: Luperini) are native to Mexico and Central America (Webster 1895). Few data, however, are published on host plant associations (Eben & Espinosa de los Monteros 2003) and natural enemies from this area (Eben & Barbercheck 1996).

In the Diabroticites (subtribe Diabroticina), the association of a number of species with plants in the family Cucurbitaceae is a well-known example for the effect of plant secondary chemistry on a plant-insect interaction (Chambliss & Jones 1966; Howe et al. 1976; Metcalf et al. 1982; Metcalf 1986). Host preferences of Diabroticites are strongly influenced by the presence of cucurbitacins (tetracyclic triterpenoids) in many wild cucurbit hosts. These non-volatile secondary compounds act as arrestants and feeding stimulants for these beetles (Chambliss & Jones 1966; Metcalf & Lampman 1989).

Furthermore, it has been proposed that Diabroticina species sequester cucurbitacins for their chemical defense. Studies of tritrophic effects demonstrated that cucurbitacins are deterrents for natural enemies such as mantids (Ferguson & Metcalf 1985), passerine birds (Nishida & Fukami 1990), the pathogenic fungus *Metarhizium anisopliae* (Moniliales: Moniliaceae) (Tallamy et al. 1998), and entomopathogenic nematodes (Barbercheck et al. 1995). On the other hand, no negative effects on general predators such as carabid larvae, mites, and centipedes (Brust & Barbercheck 1992) have been found. To date, no clear pattern has emerged from these studies. Field studies on larval host associations in the natural habitat are difficult due to the fact that Diabroticina larvae are root feeders.

Interestingly, although parasitoids are intimately associated with their hosts, and third trophic level effects of plant secondary compounds are described for a number of plant-insect associations (Gauld et al. 1992; Rowell-Rahier et al. 1995; Agrawal et al. 2002), no data exist for the cucurbit/Diabroticina/parasitoid system.

The objective of the present field study was to compare beetle abundance and diversity on two *Cucurbita* spp. that differed in presence, *Cucurbita okeechobeensis* ssp. *martinezii* L. Bailey, or absence, *C. moschata* (Lam.) Poiret, of secondary

compounds. Both cucurbits, the bitter *Cucurbita o. martinezii* and the cultivated *C. moschata*, are the most common cucurbits in the study area. Their morphology is similar, but the bitter species has smaller and paler flowers, and smaller leaves. Furthermore, the bitter species produces secondary compounds characteristic for Cucurbitaceae, the cucurbitacins (Metcalf et al. 1982; R. Ventura, unpubl. data). Moreover, parasitoid incidence in adult beetles was monitored and compared between individuals collected from the two host plants.

Material and Methods

Study Area and Host Plants

All adult insects were collected in the central zone of the state of Veracruz, Mexico. Mean annual temperature fluctuates between 18 and 25°C, with three distinct seasons: a dry-cool season (November-March), a dry-warm season (April-May) and a wet-warm season (June-October). Annual rainfall varies between 800 and 2500 mm, with a peak in the second warm season (Soto & García 1989). Common crops in the area are sugarcane, coffee, corn, squash, and beans. The original vegetation at lower altitudes is deciduous forest, whereas remnants of tropical cloud forest are found at higher altitudes (Gómez-Pompa 1977).

Within the study area, six locations for each *Cucurbita* spp. were identified. These locations were separated by at least nine km (i.e., 12 sample areas in total). They differed in altitude and climatic conditions (Table 1). To avoid collections of beetles which might recently have moved between hosts, sites with coexistence of both cucurbits were not accepted. Due to the fact that beetle abundance is affected by the presence of flowers (pers. observ.), insects were collected once or twice per week on flowering plants only. When plants began to dry out, they were replaced by others in flowering stage within the same area. At each collection date we recorded the diversity and abundance of beetles found on both plants.

Areas of approximately 100 m^2 covered by cucurbit vines were measured at each location to define the collection site.

Beetle Collection

Beetles were collected from August to December 2001 and from May to November 2002. Collection dates were based on previous studies (Rodriguez & Magallanes 1994; Eben & Barbercheck 1996; Cabrera & Cabrera 2004) which found a clear seasonality for Diabroticinas with peak abundance from early summer to fall. Plants were visually inspected for Diabroticina adults. The sampling unit was the number of beetles collected per person in one hour. Field collected adults were separated by species, location, and collection date. In order to allow for parasitoid emergence, the colonies of adult field collected beetles were maintained in the laboratory (25 ± 3°C), with a photoperiod of 13:11 (L:D), in transparent plastic containers (15 cm diameter × 25 cm length), with a gaze cover for ventilation. Beetles were fed fruits of *Cucurbita pepo* L. (zucchini) and artificial diet (Branson et al. 1975). Abundance of Diabroticina were analyzed by one-way ANOVA ($P < 0.05$) with SigmaStat™ statistical software version 2.0 (Jandel Scientific 1992-1997), after square root transformation.

Parasitism Rates

All cages with beetles were checked daily to collect and count parasitoid pupae (Eben & Barbercheck 1996). In addition, dead beetles with an entire abdomen were dissected to determine presence or absence of immature parasitoids. Percentage parasitism was calculated as the number of immature and adult parasitoids obtained for the total number of each beetle species, date, and location. Data were analyzed by a chi-square test (Zar 1999). Correlation between beetle abundance and percentage parasitism was analyzed by linear regression (Zar 1999).

Results

In the study area, *C. moschata* is cultivated for human consumption. For this reason it was commonly found along road sides and in mixed corn-squash plots, mostly in direct sunlight. *Cucurbita o. martinezii* is grown in shadier places, with oth-

Table 1. Climatic zones of the six collections areas in the state of Veracruz.

Area	Altitude (m)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Geographical location
Coatepec	1200	19.2	1926.0	19°27'N/96°58'W
Jalcomulco	340	24.0	1125.0	19°20'N/96°46'W
Naolinco	1540	16.0	1639.7	19°39'N/96°52'W
Teocelo	1160	18.1	1797.0	19°39'N/96°58'W
Tlalnelhuayocan	1640	18.0	1009.0	19°39'N/96°58'W
Xalapa	1460	18.0	1509.1	19°32'N/96°55'W

ers plants as climbing structures. It was most abundant in and around coffee plantations.

We found 17 species of Diabroticinas from five genera (Table 2). All species were collected from *C. moschata*, 15 species were collected from *C. o. martinezii*. The abundance of three species, *A. blomorum*, *D. balteata*, and *I. tetraspilota*, differed between both cucurbit hosts ($P = 3.5 \times 10^9$, $P = 0.0011$, and $P = 0.048$, respectively). The other 12 beetle species were not more abundant in any of the two host plants. Proportions of all species were different in the two cucurbits. In *C. moschata*, *Acalymma blomorum* was the most abundant beetle species, followed by *Diabrotica balteata*, *D. scutellata*, and *D. viridula*, and in *C. o. martinezii*, *Isotes tetraspilota*, *A. fairmairei*, and *D. scutellata*.

The most diverse genus was *Diabrotica* with six species in the *fucata* group, *D. balteata*, *D. dissimilis*, *D. nummularis*, *D. sexmaculata*, *D. tibialis*, *D. undecimpunctata duodecimnotata*, and three species in the *virgifera* group: *D. porracea*, *D. scutellata*, and *D. viridula*. *Diabrotica balteata* and *D. scutellata* were the most abundant species within either group. *Cerotoma atrofasciata*, *Gynandrobrotica lepida* and *G. nigrofasciata* were most common on the foliage of *C. moschata* (Table 2).

Incidence of Parasitism

The only parasitoid found was a tachinid species, *Celatoria compressa* Wulp. Parasitoids were obtained in June and July 2002 from beetles collected on the bitter cucurbit. No parasitoids were found in beetles collected on this plant in 2001. In beetles collected on the cultivated cucurbit, parasitoids were present throughout the collecting period in both years. In general, parasitoid pupae were obtained during the first 48 h after collecting the host beetle. Adult parasitoids emerged from all parasitoid pupae ($n = 169$). The presence of other parasitoids was not observed.

The tachinid parasitoid was found in three of the 15 beetle species collected on the bitter cucurbit (20%), and in 11 of the 17 beetle species collected on the cultivated cucurbit (65%). On the bitter cucurbit, the parasitoid attacked *A. blomorum*, *A. fairmairei*, and *D. balteata* at percentages of 0.9%, 7.7%, and 5%, respectively (Table 2). In the species collected on the cultivated cucurbit, *A. blomorum*, *A. fairmairei*, *A. innubum*, *C. atrofasciata*, *D. balteata*, *D. porracea*, *D. scutellata*, *D. sexmaculata*, *D. tibialis*, *D. viridula*, and *G. nigrofasciata* were parasitized. The percentage of

TABLE 2. DIABROTICINA BEETLE ABUNDANCE COLLECTED ON *CUCURBITA OKEECHOBEENSIS* SSP. *MARTINEZII* (A) AND *C. MOSCHATA*; (B) (MEAN BEETLES COLLECTED PER PERSON PER HOUR), AND PERCENTAGE PARASITISM IN THE TOTAL NUMBER COLLECTED OF EACH BEETLE SPECIES IN THE YEARS 2001 AND 2002.

	2001				2002			
	Mean		%		Mean		%	
Species	A	B	A	B	A	B	A	B
Acalymma blomorum Munroe & Smith*	3.83	50.1	0	3.7	8.17	57.71	0.9	0.6
A. fairmairei (Fabricius)	3.61	4.29	0	0.4	2.31	1.99	7.7	0.7
A. innubum (Fabricius)	0.33	5.19	0	0.8	0.15	5.78	0	0
A. trivittatum Mannerheim	0.5	2.33	0	0	0.04	3.22	0	0
Diabrotica group *fucata*								
D. balteata LeConte*	1.11	0.61	0	0	0.44	35.1	5	3.7
D. dissimilis Jacoby	0	0.04	0	0	0	0.02	0	0
D. nummularis Harold	0.11	0.74	0	0	0.02	0.09	0	0
D. sexmaculata Baly	0	0.22	0	0	0.19	0.31	0	5.9
D. tibialis Baly	0.11	0.72	0	0	0.58	14.11	0	4.6
Diabrotica group *virgifera*								
D. porracea Harold	0.5	0.24	0	0	0.23	1.81	0	2.5
D. scutellata Baly	1.65	5.54	0	1.4	3.15	1.78	0	0.8
D. undecimpunctata duocecimnotata Harold	0.39	0.06	0	0	0.08	0.01	0	0
D. viridula (Fabricius)	0.11	0.37	0	0	0.15	5.4	0	0.2
Cerotoma atrofasciata Jacoby	0	0.28	0	12.5	0.83	3.33	0	2.5
Gynandrobrotica lepida (Say)	0	0.83	0	0	0.02	0.31	0	0
G. nigrofasciata (Say)	0	1.53	0	2.5	0	0.02	0	0
Isotes tetraspilota Baly*	0.44	0.03	0	0	8.56	0.01	0	0

*Significant differences between abundance per cucurbit ($P < 0.05$), and 0: No beetles nor parasitoids were found.

parasitism in these species varied between 0.4% and 12.5% (Table 2). Highest percentages of parasitism were found in *C. atrofasciata*. No significant differences in parasitism between beetle species were detected. Also, no correlation between beetle abundance and percentage parasitism was found. We found, however, significantly higher numbers of parasitoids in beetles collected on the cultivated cucurbit ($X^2_{(1, 0.05)} = 6.46$). During the present study, parasitism was not observed in *A. trivittatum*, *D. dissimilis*, *D. nummularis*, *G. lepida*, and *I. tetraspilota*.

Discussion

The diversity of Diabroticina species on *C. o. martinezii* and *C. moschata* was similar. Nevertheless, *Diabrotica scutellata* and *Isotes tetraspilota* were more abundant on bitter *C. o. martinezii*, whereas *Acalymma blomorum* and *D. balteata* were more abundant on the cultivated *C. moschata*. *Acalymma blomorum* was the most abundant species in both *Cucurbita* spp. These results are similar to data obtained by Cabrera & Cabrera (2004) with respect to the abundance of *Acalymma* spp. in Cucurbitaceae in Argentina. Within the *fucata* group, *D. balteata* was the most abundant species, and within the *virgifera* group *D. scutellata* was dominant. These results agreed with data reported by Rodriguez & Magallanes (1994) for *D. balteata* in Tamaulipas and Veracruz, and by Eben & Barbercheck (1996) for *D. scutellata* in Veracruz. In the present study, *Diabrotica dissimilis* and *G. nigrofasciata* were not collected on the bitter cucurbit. The other 12 species had a continuously low abundance on both cucurbits.

Acalymma blomorum and *D. balteata* were collected most frequently in *C. moschata*, perhaps as a result of the high quantities of pollen in this cucurbit. We observed that the beetles visited these plants to feed on petals and flowers. *Isotes tetraspilota* was the only species that was found feeding on the leaves of *C. o. martinezii*, and it was never seen on the cultivated cucurbit *C. moschata*. *Acalymma blomorum*, *A. fairmairei*, *C. atrofasciata*, and *D. balteata* were found on the cultivated cucurbit even when the plants began to dry. *Gynandrobrotica nigrofasciata* was collected only in 2001 on the cultivated cucurbit and furthermore, in much higher numbers, on a leguminous plant (*Pachyrhizus erosus* (L.) Urban) growing in the vicinity. Fabaceae are reported as host family for this genus (Jolivet & Hawkeswood 1995).

Celatoria compressa was the only parasitoid species obtained. It was reported for the first time by Eben & Barbercheck (1996) in Diabroticite beetles. Previously, *Celatoria bosqi* Blanch. (Heineck-Leonel & Salles 1997) *C. diabroticae* Shimer and *C. crawii* Coquillett had been collected from some *Diabrotica* spp. (Chittenden 1905; Sell 1915; Gordon et al. 1987) and *A. vittatum* (Walton 1914). The differences in parasitism in the species collected on both cucurbits, three species in *C. o. martinezii* vs. 11 species in *C. moschata*, were notable and might suggest that floral odor, or secondary compounds sequestered by beetles from the bitter host plant, had an effect on the adult parasitoid. To date, no study has tried to corroborate this for parasitoids of Diabroticina beetles. On the other hand, Diabroticina beetles were more abundant on the flowers and leaves of *C. moschata*, perhaps because this species offered greater amounts of pollen than *C. o. martinezii*. Consequently, *C. compressa* might have simply responded to the abundance of host insects in *C. moschata*. In general, the incidence of the tachinid in the guild of beetle species collected in both cucurbits was low, with parasitism ranging from 0.4% to 12.5%. In an earlier study similar parasitism rates of 1.0% to 11.1% were found (Eben & Barbercheck 1996). Parasitism by *C. bosqi* in *D. speciosa* ranged from 0.1 to 30.2% (Heineck-Leonel & Salles 1997) and *C. diabroticae* parasitized *D. u. howardi* with rates of 3 to 15% (Meinke & Gould 1987; Elsey 1988).

Given our observations, it would be interesting to investigate if cucurbitacins sequestered by the beetles collected on *C. o. martinezii* function as a repellent for *C. compressa*. Our data suggest that a possible effect of plant secondary compounds is stronger on adult parasitoid behavior (i.e., host acceptance) than on immature physiology, since all parasitoid larvae that eclosed from beetles pupated and developed successfully into adults.

During the course of our study a larger number of isolated plants of the cultivated than the bitter cucurbit species was found. This situation was contrary to our observations in previous years. It might be the consequence of the rapidly declining number of coffee plantations in the central area of Veracruz. In this area, the main habitat of *C. o. martinezii* are coffee plantations, where it is found growing in a vertical fashion upon the coffee bushes as climbing structures. By contrast, *C. moschata* grows horizontally, covering bare areas exposed to plain sunlight. These differences in habitat and microclimate might have influenced the abundance and species composition of Diabroticina beetles present in both plants as well as the searching behavior of *C. compressa*.

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EFFECTS OF HOST AGE, FEMALE PARASITOID AGE, AND HOST PLANT ON PARASITISM OF *CERATOGRAMMA ETIENNEI* (HYMENOPTERA: TRICHOGRAMMATIDAE)

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ABSTRACT

Parasitism of *Diaprepes abbreviatus* (L.) eggs by *Ceratogramma etiennei* Delvare as influenced by host age, age of the female parasitoid, and host plant preference was evaluated under laboratory or greenhouse tests. Percent parasitism of *D. abbreviatus* eggs by *C. etiennei* decreased as eggs matured. The optimal age of *C. etiennei* for successful parasitism ranged from 1-2-d old. Host plant leaf thickness, leaf pubescence, and plant strata probably played a role on the parasitism by *C. etiennei*. This parasitoid is diurnal and spent approximately 5 min searching for eggs laid in cryptic locations, 46 min parasitizing an egg mass and 24 min resting. This biological information is relevant in evaluating the potential of *C. etiennei* in the classical biological control of *D. abbreviatus*.

Key Words: parasitism, *Ceratogramma etiennei*, *Diaprepes abbreviatus*, host age, parasitoid age, host plants, host preference, host-finding behavior

RESUMEN

Se estudió el efecto de edad del hospedero, edad del parasitoide, y preferencia del parasitoide a la planta huésped en el parasitismo exitoso de *Ceratogramma etiennei* Delvare sobre huevos del picudo *Diaprepes abbreviatus* (L.). El porcentaje de parasitismo disminuyó al incrementar la edad de la postura. La edad óptima de *C. etiennei* para realizar un parasitismo exitoso es 1-2 d de edad. *Ceratogramma etiennei* demostró cierta preferencia a la planta huesped en terminos de grosor de la lámina foliar, pubescencia de hojas y estrato de la planta donde se encuentren las posturas de *D. abbreviatus*. *Ceratogramma etiennei* es diurna y gasta aproximadamante 5 minutos buscando las posturas, 46 min parasitizando y 26 min descansando. La información generada durante este estudio puede ayudar a evaluar el potencial de *C. etiennei* como agente de control biológico de *D. abbreviatus*.

Translation provided by the authors.

The Diaprepes root weevil, *Diaprepes abbreviatus* (L.), is one of the major pests of citrus, vegetables, and ornamentals in Florida, Puerto Rico, and the West Indies (Beavers et al. 1983; Figueroa & Roman 1990; Sirjusingh et al. 1992). *Diaprepes abbreviatus* adults feed on the foliage of many plant species belonging to at least 30 families (Simpson et al. 1996; Adair et al. 1998). After mating, the females deposit their eggs between host plant leaves glued together with an adhesive produced by the female (Richman et al. 1983). The eggs hatch in 7-10 d and the larvae drop to the surface of the ground and feed on the roots of most host plants (Woodruff 1964; Whitcomb et al. 1982). A lack of native parasitoids attacking this weevil in Florida (Hall et al. 2001) and past failures to establish exotic parasitoids against this weevil (Beavers et al. 1980), justify further efforts to introduce, release, and evaluate candidate parasitoids for Florida (Peña et al. 1998; Peña & Amalin 2000). One of these candidates is *Ceratogramma etiennei* Delvare (Hymenoptera: Trichogrammatidae), a highly specific parasitoid to Diaprepes in Guadeloupe (Etienne et al. 1990). It was introduced into Florida from Guadeloupe in 1997 (Peña et al. 1998) and released from 1998-2000 in citrus, ornamental fields, and natural habitats infested with *D. abbreviatus*. Subsequent to release, *C. etiennei* was recovered from lime, *Citrus aurantifolia* (Christman) Swingle, and pigmy palms, *Phoenix roebelenii* O'Brien in south Florida (Table 1). However, none were recovered from 2001-2002 in the same locations. The reason for its disappearance is unknown.

This paper provides some of the information that may be involved in the host selection process by *C. etiennei*, such as host age, age of the parasitoids, and host plant preference.

TABLE 1. RECOVERY OF *CERATOGRAMMA ETIENNEI* IN FLORIDA, 1998-2000.

County	Year	Commodity	Mean % parasitism
Miami-Dade	1998	Citrus, Guava, Ornamentals	0.0
	1999	Citrus	20.2
		Guava	0.0
		Ornamental	75.7
	2000	Citrus	35.3
		Ornamental	27.6
Broward	1998	Citrus, Ornamental	0.0
	1999	Citrus, Ornamental	0.0
St. Lucie	1999	Citrus	0.0
Hendry	1999	Citrus	0.0
	2000	Citrus	0.0

MATERIALS AND METHODS

Ceratogramma etiennei used in this study was a Guadeloupe strain collected from *D. abbreviatus* eggs by J. Etienne. The colony was reared in a laboratory at 26.5 ± 1°C, 12:12 L:D, and approx 78% RH, on eggs of *D. abbreviatus* laid on strips of wax paper (Etienne et al. 1990). Adult *D. abbreviatus* used as a source of eggs were obtained from ornamentals in Homestead, Florida. Weevils were placed in Plexiglas® cages containing water, foliage of *Conocarpus erectus* L., and strips of wax paper.

Host Age Preference

Laboratory test. One to 5-d-old *D. abbreviatus* egg masses on strips of wax paper were placed randomly in an experimental arena made of translucent plastic containers (70 mm high × 70 mm long × 20 mm wide). A mated 1-d-old female *C. etiennei* was introduced into each container, provided with honey and water and host eggs of various ages. The strips with egg masses were removed after 24 h and transferred to test tubes (12 × 75 mm) separately. Tubes were plugged with Kimwipes® tissue and held 10 days for parasitoid emergence. The number of eggs per mass used in this experiment ranged from 50-100 and was replicated 20 times. Parasitized eggs were counted and percent parasitism was computed by dividing the number of parasitized eggs by the total number of eggs on each wax paper strip. Weevil eggs parasitized by *C. etiennei* have a golden chorion which is characteristic of successful parasitism (Amalin, pers. observations).

Greenhouse Test

Strips of wax paper containing 1- to 5-d-old *D. abbreviatus* eggs were randomly stapled to the upper side of leaf on 6-mo old potted *C. erectus* (height ranging from 50-65 cm) placed into a nylon mesh screen (91 cm wide × 91 cm long × 122 cm high) cage supported on a PVC frame. Ten 1-d-old mated female *C. etiennei* were released into the cage. The egg masses were collected after 24 h and processed in the same way described in the laboratory test. The test was replicated five times. Parasitized eggs from each egg mass were counted and the percent parasitism computed.

Effect of Female Parasitoid Age on Parasitism

One-day-old mated female parasitoids were provided a 3-d-old weevil egg mass on wax paper strips for 24 h in test tubes (12 × 75 mm). Egg masses were replaced daily for 9 days (i.e., until females were 10 d old). This experiment was replicated 20 times. Exposed egg masses were collected and processed in the previously described manner. Parasitized eggs from each egg mass were counted and the percent parasitism computed.

Choice Test on Selected Host Plants

Four 1-yr-old host plants, namely, lime (*Citrus aurantifolia*), green buttonwood (*Conocarpus erectus*), silver buttonwood (*Conocarpus erectus* variety *sericeus* Fors. ex. DC), and pigmy palm (*Phoenix roebelenii*) were tested to determine their effects on parasitism by *C. etiennei*. Four plants, one per species were placed into screen cages (3 m × 2 m × 1 m) along with 100 adult weevils (50:50 ♂:♀). The plants were removed after 3 d, leaving twenty egg masses per host plant. All plants were then placed in another screen cage (1 m × 1 m × 1.22 m) and arranged in a 1 m × 1 m square. About 1000 1-d-old *C. etiennei* adults (1:0.60 ♀:♂ ratio) were released within the cage in the middle of the square. Egg masses found on each host plant were collected three days later and processed as above. The experiment was replicated three times. Percent parasitism was computed. Leaf thickness and pubescence were also compared between the test host plants.

Effect of Plant Strata on Parasitism

Wax paper strips with two d-old weevils (n = 5 per stratum) were stapled to the upper, middle

and lower canopy of 6-mo-old potted *C. erectus* and introduced into a nylon mesh screen cage (91 cm wide × 91 cm long × 122 cm high) supported on PVC frames. Ten 1-d-old female and 5 male parasitoids were released inside the cage. Egg masses were collected after 24 h and placed in individual test tubes as described above. This test was replicated four times. The number of parasitized eggs was counted after 10 days.

Host Finding Behavior Video

Host finding behavior of *C. etiennei* was observed in a Petri plate (60 × 15 mm) under a stereoscopic microscope with attached camera (Videoflex®) and connected to a television monitor (TV) (RCA®) and video recorder (RCA®). A 3-d-old *D. abbreviatus* egg mass and a 2-d-old mated *C. etiennei* female were placed in a plate for observation during daytime (1000 to 1400 h) and nighttime (1700 to 2100 h). The set-up was repeated five times with different individuals. The recorded data were collected, managed, and analyzed with the Observer Videopro 4.1 program (Noldus Information Technology®).

Statistical Analysis

Data from selected experiments were analyzed for significant differences by the general linear model procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Data transformations were performed on selected experiments. Means were compared by Duncan's multiple range test (DMRT).

Results

Host Age Preference

Percent parasitism by female *C. etiennei* was significantly different among host age in both laboratory and greenhouse tests. Three-d-old weevil eggs were most acceptable to the parasitoids under laboratory and greenhouse conditions (Table 2).

Effect of Female Parasitoid Age on Parasitism

Mean egg parasitism by female *C. etiennei* was affected by parasitoid age (Table 3). Percent parasitism significantly increased for 1- to 2-d-old females, but decreased thereafter. Parasitism reached a plateau when females were 3- and 4-d-old, and declined for 5- to 9-d-old females. By the 10th day, all parasitoids were dead.

Choice of Host Plant

The highest percent parasitism of weevil eggs by *C. etiennei* was found on pigmy palm followed by green buttonwood and lime (Fig. 1). The lowest parasitism was recorded on silver buttonwood. Variation in parasitism for different host plants is probably influenced by the leaf thickness and pubescence. For instance, leaf thickness for silver buttonwood (0.48 ± 0.01 mm) and green buttonwood (0.45 ± 0.01 mm) is higher (df = 3,76; F = 81.44; P = 0.001) than lime (0.23 ± 0.01 mm) and pigmy palm (0.23 ± 0.01 mm). At the same time, pubescence is higher for silver buttonwood (3186 ± 422 trichomes/mm^2) than green buttonwood (14.80 ± 1.58 trichomes/mm^2), lime, and pigmy palm (0.00 ± 0.00 trichomes/mm^2).

TABLE 2. EFFECT OF AGE OF *D. ABBREVIATUS* EGGS ON ACCEPTANCE BY *CERATOGRAMMA ETIENNEI* UNDER GREENHOUSE AND LABORATORY CONDITIONS.

Egg age (days)	% Mean Parasitism ± S.E.*	
	Laboratory test	Greenhouse test
1	0.53 ± 0.36 b	1.87 ± 1.86 ab
2	0.89 ± 0.59 ab	3.46 ± 0.11 a
3	2.15 ± 0.72 a	3.38 ± 0.28 a
4	1.76 ± 0.72 ab	2.60 ± 1.30 ab
5	0.40 ± 0.28 b	0.00 ± 0.00 b

*Means with the same letter are not different according to Duncan's multiple range test (DMRT) at $P \leq 0.05$. Data analysis was performed after log transformation.

Effect of Plant Strata on Parasitism

Higher parasitism was detected in eggs found in the lower (85.15 ± 3.98) and middle strata (75.14 ± 3.44) rather than the upper portion (49.73 ± 4.51) of the plant (df = 2,52; F = 4.82; P < 0.01) (Table 2). Peña et al. (unpubl.) found that *D. abbreviatus* deposits more eggs on the upper and middle plant canopy than on the lower canopy of silver buttonwood.

TABLE 3. PERCENT PARASITISM BY *CERATOGRAMMA ETIENNEI* AS INFLUENCED BY AGE OF THE PARASITOID.

Age of female *C. etiennei* (days)	Mean % egg parasitism (± S.E.)*
1	59.35 ± 3.71 b
2	80.04 ± 2.90 a
3	52.87 ± 2.79 b
4	52.46 ± 2.50 b
5	30.03 ± 3.58 c
6	12.13 ± 2.50 d
7	4.74 ± 1.63 de
8	0.76 ± 1.10 e
9	0.00 ± 0.00 e

*Means with the same letter are not different according to Duncan's multiple range test (DMRT) at $P \leq 0.05$.

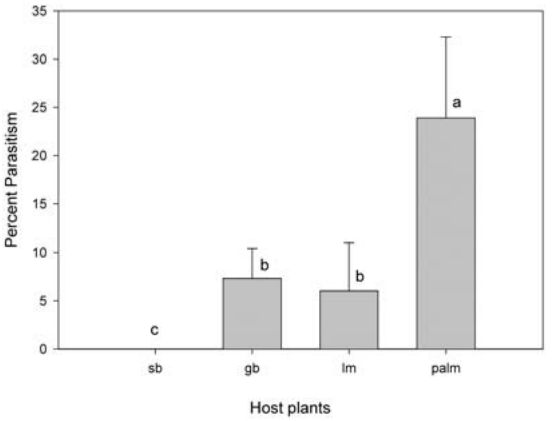

Fig. 1. Percent parasitism by *Ceratogramma etiennei* on various host plants. Notes: sb = silver buttonwood, gb = green buttonwood, lm = lime, and palm = pigmy palm. (Note: Bars with the same letter are not different according to Duncan's multiple range test (DMRT) at $P \leq 0.05$).

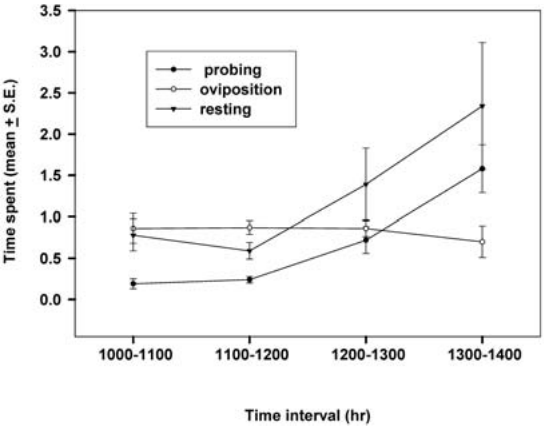

Fig. 2. Parasitism activities by *Ceratogramma etiennei* (a 4-h observation during daytime). The vertical scale showing time spent is in hours.

Host Finding Behavior Analysis

Video recording during the diurnal and nocturnal period showed that *C. etiennei* parasitizes its hosts only during daytime. Parasitism activities recorded showed three types of behavior from the time of host detection to departure from the host. These were probing (walking and antennation), oviposition (drilling and egg laying), and departure (resting). The average duration in hours of a single act of each behavior is as follows: walking (0.15 ± 0.10), antennation (0.08 ± 0.01), drilling (0.15 ± 0.01), egg laying (0.31 ± 0.02), and resting (0.24 ± 0.16). In probing, a female walked back and forth around the host, while drumming with its antennae. Once the egg mass was located, the female drilled a hole through the leaf and egg chorion to lay an egg within the weevil egg. Oviposition punctures were visible on parasitized eggs. The results of the 4 h observation period are shown in Fig. 2. Probing by the female was faster during the first 2 h of the act, but oviposition took longer initially. Resting time decreased in time. These observations suggest that host finding and acceptance (probing) was faster during first encounter with a fresh egg mass. Dissection of the parasitized eggs showed that more than one egg was deposited by *C. etiennei* periodically; however, only one parasitoid developed per host egg.

Discussion

Results of our experiment on the host age preference showed that host age can affect choice of the parasitoids. *C. etiennei* appears to prefer younger eggs for parasitism. Similar result has been obtained on other trichogrammatids (Schmidt 1994). For instance, emergence rate of *Trichogramma chilonis* Ishii significantly decreased when eggs were older than 48 h at the time of encounter (Guang & Oloo 1990; Schmidt et al. 1999). The host age at the time of parasitism appears to have implications on fitness of progeny (Sequeira & Mackauer 1992, 1994) and parasitoids, which preferentially attack younger host stages (Hagvar & Hofsvary 1986; Sequeira & Mackauer 1988). The results obtained from the host age preference experiment provide relevant information regarding mass rearing of *C. etiennei.* To maximize *in vivo* parasitoid production, *C. etiennei* females should be provided with *D. abbreviatus* egg no older than 3 d.

The age of the parasitoid is also crucial on successful parasitism. A younger parasitoid is more fecund than the older ones. The effect of age of the parasitoid on their ability to parasitize their host has been documented on some parasitoids (Hentz 1998; Honda 1998). For instance, the optimum age for *Cotesia marginiventris* (Cresson), to successfully parasitize larvae of *Spodoptera frugiperda* (J.E. Smith) ranges from 48 to 96 h (Rajapakse 1992). *C. marginiventris* younger or older than the above age were not able to parasitize a host. Similar result has been shown in our experiment on the effect of female parasitoid age on parasitism, in which higher parasitism was exhibited by 1- to 2-d-old *C. etiennei*. Knowing the age of the parasitoids when they are most fecund is very important in deciding what age of the parasitoids to release in the field to obtain a meaningful level of parasitism.

Another factor that affects parasitism is the location of the host. Insect hosts in cryptic location provide a challenge for successful parasitism. For instance, *D. abbreviatus* eggs are deposited in between two leaves. The female parasitoid has to drill through the abaxial and adaxial surfaces of the leaf to reach *D. abbreviatus* eggs; therefore,

successful oviposition may be facilitated when weevil eggs are deposited on leaves with thinner blades and non-pubescent foliage, such as pigmy palm. These leaf features might explain why *D. abbreviatus* eggs on silver buttonwood were the least parasitized among the four host plants. Variation in parasitism on various plants was also observed by Peter (1990). He found that maximum parasitism by *Apanteles taragamae* Viereck on *Diaphania indica* (Saunders) was recorded on two varieties of cucurbits with smoother leaves. Physiological factors (i.e., leaf odor) cannot be ruled out.

Ceratogramma etiennei search, find, and attack their host in cryptic locations, however, the cues they use to find *D. abbreviatus* eggs are still unclear. Short range and contact chemical cues associated with physical cues arising from the host plants or from the host are reported to affect host recognition and acceptance by some parasitoids. This might also be true for *C. etiennei*. Preliminary tests showed that chemical and physical cues play an important role in host recognition by *C. etiennei* (D. Amalin et al. unpublished data). The chemical cues can be found on scales from the weevil elytra, usually left behind near the egg mass by the female during oviposition, on adult feces, or on the substance produced by the female to cement the eggs between leaves. Further studies to identify the factors involving host recognition and host acceptance by *C. etiennei* are worth investigating.

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EFFECT OF ELEVATION AND HOST AVAILABILITY ON DISTRIBUTION OF STERILE AND WILD MEDITERRANEAN FRUIT FLIES (DIPTERA: TEPHRITIDAE)

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ABSTRACT

Effects of elevation and host fruit availability on the distribution of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), were evaluated with cylindrical traps baited with a female-biased food-based synthetic lure. Tests were conducted in the Santa María valley, Guatemala during a sterile male release program. Traps were placed in or near host trees (primarily coffee and citrus) and in non-host trees when no hosts were available. Trap locations were grouped according to elevation every 170 m. Elevation group midpoints were 1103, 1273, 1443, and 1613 m above sea level. The spatial distributions of sterile males, wild males, and females were clumped throughout the 13 wk of sampling. More wild female flies were captured in coffee in the 1273 m elevation and on non-host trees in the 1103 m elevation. The number of wild males was directly related to the number of wild females captured, and the sex ratio (female: male) was highest at the 1443 and 1613 m elevation ranges. There was no relationship between the number of sterile males and number of wild females in the traps at any elevation. At all elevation ranges, an inverse relationship was observed between the numbers of wild females and males with the mean numbers of sterile males per trap. Wild *C. capitata* populations appeared to decrease when 40 sterile males were captured per trap with wild females per week. The results indicated that, during the sampling period evaluated, coffee appeared to be the main host plant for the wild population, *C. capitata* were more abundant at the 1273 m elevation range than at other elevations. Additional or alternative host species may harbor the female population at other times.

Key Words: *Ceratitis capitata*, fruit fly host plant, elevation, sterile insect technique, fruit fly spatial distribution.

RESUMEN

Plantas hospederas y elevación preferencial por la mosca Mediterránea de la fruta, *Ceratitis capitata* (Wiedemann), fueron evaluadas con trampas cilíndricas con cebo sintético que atrae hembras. Experimentos fueron realizados en Guatemala durante el programa de liberación de machos estériles. Trampas fueron colocadas en o cerca de árboles hospederos (principalmente café y cítricos) y en otros árboles no hospederos). Las trampas fueron agrupadas de acuerdo a su elevación cada 170 m, en los rangos de elevación 1103, 1273, 1443, y 1613 m por encima del nivel del mar. La distribución espacial de los machos estériles, hembras y machos fértiles y salvajes fue agrupada a través de las 13 semanas de muestreo. Las hembras salvajes fueron capturadas sólo en café (más en el rango de elevación 1273) y en las plantas no identificadas (más en el rango de elevación 1103). El número de machos salvajes fue proporcional al de hembras salvajes y el radio sexual (hembra: macho) fue mayor en los rangos de elevación 1443 y 1613. El número de machos estériles no fue afectado por el incremento de hembras salvajes en las trampas. En todos los rangos de elevación, se encontró una relación inversa entre el número promedio de hembras y machos salvajes con el número promedio de machos estériles. La población salvaje de la mosca del mediterráneo decreció cuando los machos estériles llegaron a ser 40 por trampa con hembras salvajes por semana. Los resultados indicaron que el café pareció ser la planta hospedera principal de la población salvaje durante el período de muestreo, y que durante este, las moscas del Mediterráneo fueron más abundantes en el rango de elevación de 1273 m que en otros rangos de elevación. Otras plantas hospederas alternativas podrían acarrear a la población de hembras salvajes en otros momentos.

Translation provided by the authors.

Ceratitis capitata (Wiedemann), the Mediterranean fruit fly, is considered the most destructive agricultural pest in the world. Even though it is not established in the continental U.S., its potential impact on the California and stone fruit industry has been projected to be about $0.5-1 million in agricultural losses per year (Siebert & Pradhan 1990). It has been reported to attack more than 260 species of fruits and vegetables world-wide (Liquido et al. 1991; Ovruski et al. 2003). Adult females damage fruit by depositing their eggs in holes made under the skin of the fruit. Availability of host plants suitable for oviposition is a key factor for understanding the population dynamics of the fruit fly and its distribution over space and time. This information can be used for planning management strategies for this pest. If the plants are not in fruit or have only low quality fruit, mature females either arrive in low numbers or emigrate rapidly and fly considerable distances before finding host plants with acceptable fruits (Prokopy & Roitberg 1989). Therefore, availability of host plants is considered a key factor in the temporal pattern of fruit fly abundance (Bess et al. 1963; Newel & Haramoto 1968; Malavasi & Morgante 1981; Vargas et al. 1983).

Successful eradication of the Mediterranean fruit fly has been obtained by the sterile insect technique (SIT) in combination with bait sprays in Mexico, and in the U.S. in California and Florida (Vargas 1989). Endemic populations of *C. capitata* occur in Guatemala, where efforts to suppress fruit fly populations in large portions of the country are occurring through the Programa Moscamed, a trilateral effort of the governments of the U.S., Mexico, and Guatemala (Linares & Valenzuela 1993). The primary effort in Guatemala is to maintain a barrier to prevent movement of *C. capitata* into Mexico and the U.S. The areas under SIT activity include a fly free area (57% of area, located in the northwest, closest to the border with Mexico), an infested area (33.8% of area, located in the southeast, where high populations of *C. capitata* are present) and a control area (9.2% of area, located between the free area and the infested area) (Linares & Valenzuela 1993). Traps are placed throughout this area and are monitored by Moscamed, and trapping data indicate that up to 98% of the region is under successful control, with no wild flies captured. However, localized isolated populations or "hot spots" of wild flies still persist in the infested area, and identification of the factors responsible for the hot spots is critical to the success of the eradication effort. The Santa María area of Guatemala is located close to the southeast edge of the infested area, and contains isolated populations of *C. capitata*. A study was initiated to evaluate the spatial distribution of endemic wild and released sterile *C. capitata* in this area and to identify effects due to elevation and host plant availability.

Materials and Methods

Traps and Lures

Cylindrical open-bottom dry traps (OBD; Heath et al. 1996) were baited with a three component lure consisting of ammonium acetate, putrescine, and trimethylamine, formulated as three separate patches backed with adhesive for securing inside the trap (Suterra, Inc., Bend, OR). The OBD trap (9 cm diam by 15 cm tall) is made from opaque green waxed cardboard and has three holes (2 cm diam) evenly spaced around the midline of the trap body. A yellow sticky insert (7.6 by 12.7 cm; Suterra LLC, Bend, OR) was hung inside the center of the trap to retain flies. Sticky inserts were replaced weekly, the three component synthetic lures were replaced every 4 wk, and traps were replaced when the cardboard deteriorated.

Fly Release

The sterile male-only *tsl* strain of *C. capitata* (Vienna-7) used in this study was produced by gamma irradiating pupae with 10Krad (100 gray) at the Moscamed rearing facility, Guatemala. Irradiated pupae were treated with 4g/liter of pupae with powdered florescent dye (Dayglo Color Corporation, Cleveland, OH) to mark the adults on emergence. *C. capitata* adults were kept at 23°C and fed a mixture of 15% sugar and 84.99% water thickened by 0.01% agar. At three to four days of age, flies were chilled to near 0°C, loaded into chilled-fly release machines (K&K Aircraft, Bridgewater, VA) installed in a Cessna Caravan, and released at an average rate of 3,600 flies per ha over the test area from an altitude of 2500 to 3000 m above sea level.

Protocol for Field Trial

The study was conducted in a geographically diverse area of Guatemala under SIT activity. The field site was approximately 20 km^2 and was centered at longitude -91.53° and latitude 14.71° in the Santa María valley between the Santa María and Santo Tomas volcanoes in the province of Quetzaltenango. Fifty-one traps were deployed throughout the valley at different elevations and host plants to monitor the presence of the wild populations and the sterile males released in the area. Trap sites were determined by generating a grid of potential trap locations based on a point in the center of the valley and spaced evenly 500 m apart. Traps were then placed as close to these potential trap locations as possible with GPS (Garmin International, Inc., Olathe, KS, GPS III Plus). A potential trap location was one that had road access, where the terrain (rivers, mountain, etc.) did not interfere with trap deployment, with

a known history of detection of *C. capitata* or where attack was likely due to phenology of known hosts or presence of wild alternative hosts. Potential trap locations were eliminated if they were inaccessible to the trappers, if they were bare of trees or structures to support a trap, or if permission for access was not granted. Traps were placed primarily in or near host trees, including coffee (*Coffea arabica* L.), or trees within a coffee grove, sweet orange (*Citrus sinensis* Osbeck), nispero (*Manilakara zapata* [L.] P. Royen), guava (*Psidium guajava* L.), mango (*Mangifera indica* L.), apple (*Malus pumila* P. Mill), melon (*Cucurbita melo* L.), and loquat (*Eriobatyra japonica* Lindl.). If no host trees were near the prospective location, a trap was placed in a non-host tree. Elevation of the traps varied from approximately 1,000-1,700 meters above sea level, and this range was divided into four equal groups of 170 m to determine elevation groups. Elevations (elevation ranges) were designated by their midpoint, and considered as 1103 m (1017-1187), 1273 m (1187.1-1357), 1443 m (1357.1-1527), and 1613 m (1527.1-1697).

The traps were sampled weekly for 13 wk from June to October 2002 (recorded as wk 26-38 out of 52 wk per year). During this time only a few hosts such as guava, citrus, and coffee were fruiting and available for *C. capitata* colonization. All flies captured were taken to the Moscamed laboratory in Mazatenango, Guatemala, examined to determine sex and sterility status following standard protocols (Anonymous 1983), and number of sterile males, wild males, and females were recorded. Meteorological data was not available.

Host Fruit Availability

Information on host fruit availability in the Santa María valley was obtained from records maintained by Moscamed. As part of the Moscamed protocol, fruit sampling is carried out in an extensive way to complement trapping (Linares & Valenzuela 1993), and host fruits are obtained from all places including urban, rural, wild, agricultural, and cultivated areas. Sampling routes are determined according to location of fruit trees inside private properties, access areas, and roads. Fruits were collected directly from trees when they were mature but still with solid (or firm) consistency. Sampling numbers varied according to fruit: 30-60 coffee or cherries, and 4-6 for other fruit trees. If pest levels are low, only fruits susceptible to the *C. capitata* attack with circular yellow or necrotic spots are collected. If many trees are present, samples are taken from different trees as long as they are not separated by more than 100 m. If fruits are scarce, they are collected from known hosts or from those that had higher probability of infestation, i.e., from the sunny side of the host plant at different heights. Historical data on collection dates and number of mature fruit sampled per collection date were used to estimate pattern of host fruit availability in trees used for trap placement in this study. Infestation levels were not recorded.

Data Analysis

Data were checked for homocedasticity prior to statistical analysis. To normalize the data and stabilize the variance, numbers of fruit flies captured per trap per week were square root-transformed ($x + 0.5$) and a repeated measure ANOVA was used to detect effects of sampling date and elevation range on female-male ratio. To detect differences in trap captures among different hosts and elevations, and to compare female:male ratio among elevation ranges, a Kruskal-Wallis ANOVA was used followed by a non-parametric multiple comparison procedure (Siegel & Castellan 1988) when no transformation normalized the data (SAS Institute 1998). The variance to mean ratio of the numbers of fruit flies captured each week sampled, for each fruit fly type (wild female, wild male, and sterile male) was used to determine the fruit fly spatial distribution (Southwood 1978).

Results and Discussion

Number of traps was variable at each elevation range and host plant. Traps were deployed on 25 non-host species, 24 coffee trees, one loquat and one orange tree (*Citrus* spp.). On coffee, 4, 14, 3, and 3 traps were deployed at the 1103, 1273, 1443, and 1613 m elevation ranges, respectively. On non-host species, 2, 4, 10, and 6 traps were deployed at the 1103, 1273, 1443, and 1613 m elevation ranges, respectively. In the 13 wks of sampling, wild females were captured in 5, 68, 6, and 9 traps on coffee and in 3, 1, 6, and 3 traps on non-host species at the 1103, 1273, 1443, and 1613 m elevation ranges, respectively. Five traps also were deployed above 1697 m, but no wild or sterile flies were ever captured in those traps. Therefore, these five traps were not considered in the analyses.

Because the wild females are the target for control and zero values confounded the results (no statistical differences were detected among elevations, plant species or between wild females or males, and sterile males), only traps that captured wild females were used in the analyses. The only traps that captured wild females were those traps deployed on coffee and non-host species. Table 1 shows the number of traps for each sampling date and for the 13 wks of sampling, and the average number of wild females, wild males, and sterile males captured at different elevations and host plants. The highest percentage of traps with wild females was found on coffee at the 1273 m elevation range, representing 41% of the traps that

TABLE 1. PERCENT OF SAMPLES WITH WILD FEMALES (OUT OF TOTAL NUMBER OF TRAPS TIMES NUMBER OF SAMPLES (13 WEEKS)) IN EACH ELEVATION GROUP AND IN EACH HOST GROUP, AND NUMBER OF *C. CAPITATA* CAPTURED IN TRAPS PLACED IN COFFEE. TESTS WERE CONDUCTED FROM JUNE TO OCTOBER 2002, IN SANTA MARIA, GUATEMALA.

Elevation range (m)	Coffee	*n*	Non-host species	*n*	Average (±SE) number of flies per trap per week		
					Wild females	Wild males	Sterile males
1103	10.4% (52)	4	12.5% (26)	2	1.0 ± 0.0 b	0.5 ± 0.2 b	10.8 ± 4.8 a
1273	40.5% (182)	14	2.1% (52)	4	5.4 ± 1.1 a	3.8 ± 0.9 a	26.1 ± 3.3 a
1443	16.7% (39)	3	5.0% (130)	10	3.0 ± 0.7 ab	0.6 ± 0.3 ab	16.2 ± 3.8 a
1613	25.0% (39)	3	4.2% (78)	6	1.9 ± 0.6 ab	0.5 ± 0.2 b	10.8 ± 1.9 a

Means in the same column followed by the same letters are not different (Kruskal-Wallis ANOVA, $P < 0.05$); *n* represents the total number of traps deployed on each host at each elevation range.

captured females. Captures of wild females at this elevation range were not significantly different than those captures at the 1443 and 1613 m elevation ranges but were higher than those at the 1103 m elevation range. Similar results were obtained for the wild males. The mean number of sterile males in traps with wild females on coffee was not significantly different among elevation ranges (Table 1). On the non-host trees, the highest percentage of traps with wild females was found at the 1103 m elevation range but this effect of elevation was not significant (Table 1, $H = 0.241$; $df = 3$, $P = 0.9708$). Findings of sterile males in comparable numbers at all elevation ranges may indicate that the sterile release program was successful in distributing the flies adequately to pursue an effective control of the wild female populations.

The peak of maturation for all the host plants available for *C. capitata* colonization was in mid May, and maturation rapidly decreased by the end of the summer. During late June, when this experiment began, host plants such as caimito (*Chrysophyllum cainito* L. (syn. *Achras caimito* Ruiz & Pavon)), mango, and mandarin (*Citrus reticulata* L.) only had a few mature fruits left on the trees. Coffee, sweet orange, sour orange (*Citrus aurantium* L.), and guava trees had the highest numbers of ripe fruits among the host plants evaluated at the end of June and throughout the experiment. Only guava, citrus (*Citrus* spp.), and coffee were fruiting and available for *C. capitata* colonization during the sampling period. No information was collected on the phenology of the trees where the traps were deployed. Therefore, we cannot infer the relation between host availability and trap captures.

The spatial distributions of sterile males, wild males, and wild females were clumped throughout the sampling period as indicated by the variance to mean ratio (Table 2), except on wk 38 when the sterile males appeared to be distributed at random. However, the overall spatial distribution of the sterile males was clumped. Previous studies also found a patchy distribution of the Mediterranean fruit fly under low population densities (Bateman 1972; Vargas et al. 1983; Nishida et al. 1985; Harris & Lee 1986, 1987; Harris et al. 1993; Papadopoulos et al. 1996; Prokopy et al. 1996; Israely et al. 1997; Katsoyannos et al. 1998; Papadopoulos et al. 2001).

Figure 1 presents the population dynamics of the wild females at the four elevation ranges on coffee and on the non-host trees. Even though the wild females appeared on both host and non-host trees at the beginning of the study (wk 26-30), they disappeared from the non-host trees after wk 32 and increased on coffee at all elevations. This observation might be an indication that while coffee and non-host trees are flowering or ripening, *C. capitata* populations use both tree species, but when ripening of coffee occurs on wk 33 and no other fruits or flower plants are available at this time, the female flies move to the

TABLE 2. MEAN/VARIANCE RATIO TO DETERMINE THE SPATIAL DISTRIBUTION OF *CERATITIS CAPITATA* CAPTURED IN CYLINDRICAL TRAPS BAITED WITH A FOOD-BASED SYNTHETIC ATTRACTANT IN SANTA MARIA, GUATEMALA.

Week	Wild females	Wild Males	Sterile males
26	0.02	0.03	0.04
27	0.09	0.00	0.02
28	0.10	0.37	0.21
29	0.42	0.61	0.01
30	0.24	0.29	0.01
31	0.46	0.80	0.02
32	0.11	0.12	0.03
33	0.06	0.09	0.03
34	0.10	0.08	0.03
35	0.31	0.16	0.15
36	0.61	0.49	0.81
37	0.22	0.50	0.52
38	0.45	0.57	1.04
Total	0.05	0.06	0.02

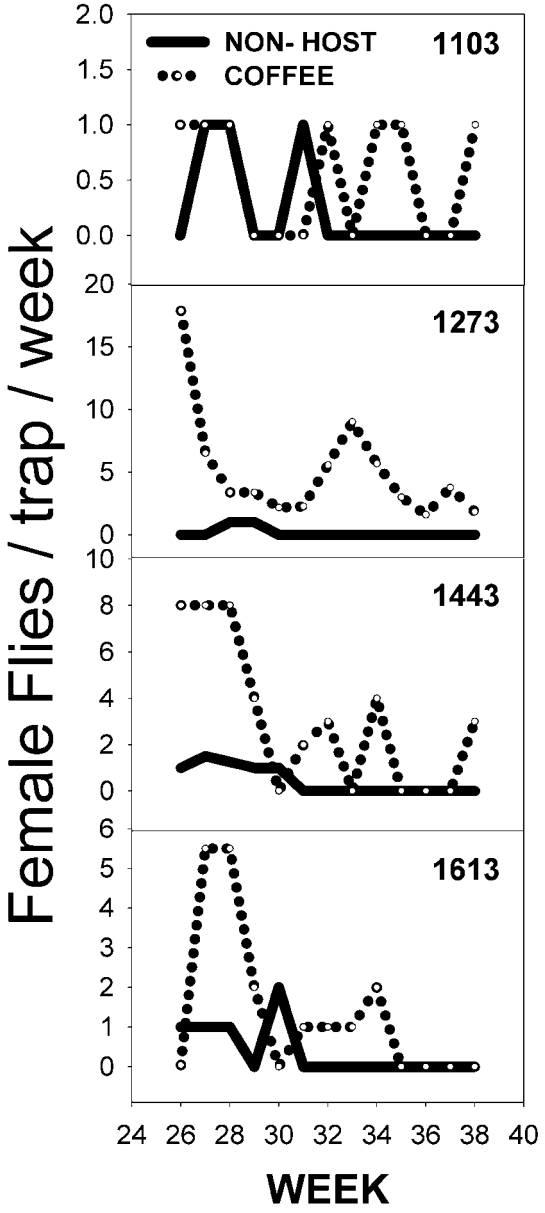

Fig. 1. Population dynamics of wild female *C. capitata* captured in cylindrical traps baited with food-based synthetic attractant during 12 weeks of sampling at different elevation ranges on coffee (dotted line) and non-host trees (solid line) in Santa María, Guatemala.

coffee areas in search of better feeding and oviposition sites. This observation agrees with Papadopoulos et al. (2003) findings that the Mediterranean fruit fly females aggregate in space in response to the changing phenology of host trees and to the sequential availability of ripe or semi-ripe fruits in an orchard. Moreover, *C. capitata* are known to adjust their foraging behavior in response to the changes in the spatial, temporal, and seasonal distribution of food and other resources (Hendrichs et al. 1991).

Because captures in traps on non-host trees were less than two females per trap per week for most of the study, only data from traps in coffee were used in the remaining analyses. A direct relationship between the mean number of wild females and males was found at different elevation ranges on coffee (Fig. 2). The number of wild males was directly proportional to the number of wild females, but the female:male ratio varied among elevation ranges ($F = 22.809$; $df = 1, 47$; $P < 0.001$). The highest female:male ratios were 4.0

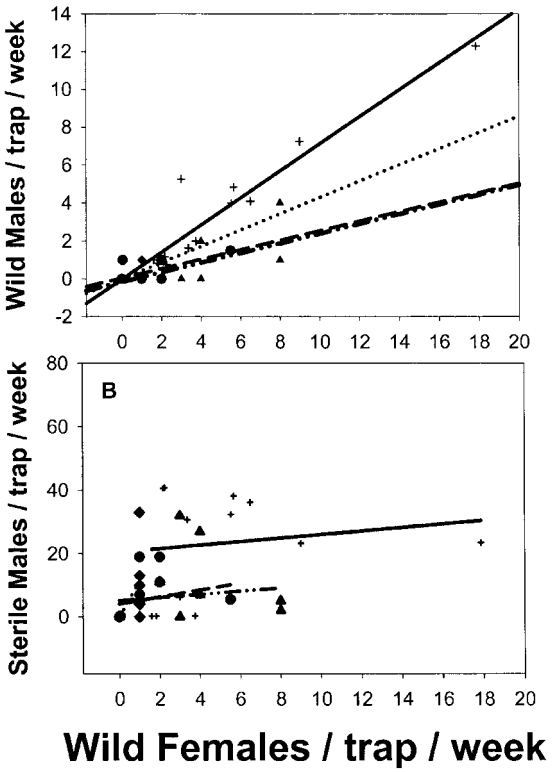

Fig. 2. Relationship between (A) mean number of wild female and male *C. capitata* and (B) mean number of wild female and sterile male *C. capitata* captured in cylindrical traps baited with food-based synthetic attractant and placed in coffee trees at different elevation ranges (◆:1103 m, +:1273 m, ▲:1443 m, •:1613 m above sea level) in Santa María, Guatemala. Lines indicate regression lines for 1103 m (– – –), 1273 m (——), 1443 m (– · · –), and 1613 m (· · ·). For wild-males/trap/week vs wild females/trap/week: $y = 0 + 0.43x$ ($r^2 = 0.26$, for 1103 m); $y = -0.19 + 0.71x$ ($r^2 = 0.89$ for 1273 m); $y = -0.17 + 0.26x$ ($r^2 = 0.47$, for 1443); $y = 0.04 + 0.25x$ ($r^2 = 0.63$, for 1613 m). For sterile males/trap/week vs wild females/trap/week $y = 11.14 + 0.36x$ ($r^2 = 0.37$, for 1103 m); $y = 20.50 + 0.56x$ ($r^2 = 0.02$, for 1273 m); $y = 5.08 + 0.50x$ ($r^2 = 0.02$, for 1443 m) and $y = 4.03 + 1.10x$ ($r^2 = 0.10$, for 1613 m).

± 2.0 and 2.3 ± 0.6 (mean ± SE) at the 1443 and 1613 m elevations, respectively. No relationship was detected between the number of wild females captured and the number of sterile males captured when all the elevations were considered (ANOVA, $F = 1.763$; $df = 1, 47$; $P = 0.1671$). However, after separating the sterile male and wild female captures by elevation range (Fig. 3.) an inverse relationship was observed between the numbers of wild females and sterile males per trap at the 1273 m elevation range. This is an additional indication that the sterile releases were successful in controlling the wild female populations. When the sterile males reached 40 per trap with-wild-females per week, a corresponding reduction was observed in the wild population of females (Fig. 3). A successful SIT program requires releasing enough sterile flies so that at least an overflooding ratio of 100 sterile males is reached for each wild fly captured (Garcia et al. 1999; Barry et al. 2003). This evaluation is averaged over all traps, also including those that do not capture any wild females. Furthermore, it is based on fly captures on Jackson traps that target only male flies. In this study, OBD traps were used for the analyses. Therefore, the discrepancy in numbers (40 versus 100) may be due to the exclusion of traps with zero-wild-females, and to the use of female biased traps resulting in an overflooding ratio below the required average. Because the wild female populations decreased at 40 sterile males per traps-with-wild-females, this may be an indication that the required overflooding ratio of 100 sterile males per wild female per trap captured was reached. Additional studies are required to adjust the over-flooding ratio based on OBD traps. Elevation effects have been observed with other tephritid species. For example, the melon fly, *Bactrocera cucurbitae* (Coquillet), is found mostly at low and medium altitudes in Reunion Island where it competes with the Ethiopian cucurbit fly, *Dacus ciliatus* Loew, both competing with the Indian Ocean cucurbit fly, *Dacus (Dacus) demerezi* (Bezzi) that occupies high altitude areas (Etienne 1972; Vayssieres & Carel 1999).

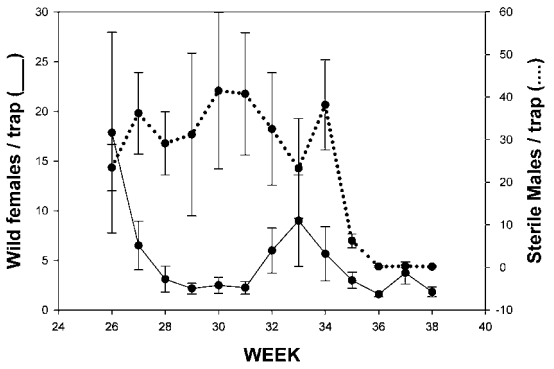

Fig. 3. Mean number of sterile males per week in traps with wild females (•••), and sterile male *C. capitata* (——) per week at the 1273 m elevation range.

After wk 32, numbers of sterile males decreased in all traps and the numbers of females began to increase at all elevation ranges. On wk 34, a decrease of the sterile males in the traps was observed, and an increase of the wild females occurred by wk 37. The inverse relationship of the sterile males and the wild populations of *C. capitata* is an indication that the aerial releases of sterile *C. capitata* were successful in reducing the wild populations in Santa María, Guatemala. This result reiterates previous eradication efforts of this pest at the Mexico-Guatemala border, which prevented the northward spread of the fly into Mexican territory (Orozco et al. 1994).

Data from this study support the hypothesis that elevation and host fruit availability affect the distribution of wild flies in the habitat of this valley. Wild male and female fruit flies were more abundant at the 1273 m elevation range on coffee throughout the sampling period. Even though higher mating success of sterile males was reported at low elevation sites (700 m) in Guatemala (Shelly et al. 2003), it is important to direct *C. capitata* control efforts with SIT to those areas where the wild populations persist as "hot spots" at higher elevations. Micro-environmental differences in humidity and temperature, as well as host fruit maturity, may have contributed to creating the favorable conditions for wild fruit flies. Microclimatic environmental parameters that regulate clumped distribution of the wild fruit flies remain to be identified.

Because the number of samples was unbalanced among elevation ranges, a balanced sampling scheme on coffee and other host plants among elevation ranges is needed to identify other possible host plant preferences by *C. capitata* wild populations. Furthermore, detailed information of fruiting phenology needs to be recorded to determine which host plants play a key role in the *C. capitata* population increases (Ovruski et al. 2003). We hypothesize that different available hosts harbor populations of different sexes, as reported by Papadopoulos et al. (2003), and also that different micro-environmental conditions (Eskafi & Kolbe 1990) may favor the survivorship of different fruit fly sexes. Because several factors may be interacting and affecting the spatial distribution of *C. capitata* in this area, micro-environmental conditions and fruit availability at different elevation ranges are needed to test these hypotheses that may explain the variation in sex ratios at different elevation ranges. Although coffee appeared to be the main host plant for the wild population during the sampling period reported herein, additional or alternative host species may harbor the female population at other times.

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INTERCROPPING WITH SUNFLOWERS TO ATTRACT BENEFICIAL INSECTS IN ORGANIC AGRICULTURE

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ABSTRACT

Sunflowers (*Helianthus* spp.) are listed in many extension factsheets and other such publications as excellent plants to attract beneficial insects in addition to those known to be important pollinators. We performed a 2-year study at a number of organic farms in Alachua County, Florida to determine if the presence of sunflower rows included in a polyculture system increased the occurrence and abundance of beneficial insects in cropped fields. The occurrence of beneficial insects was significantly greater on sunflower than on crop vegetation in control blocks and crop vegetation greater than 10 m distant from sunflowers. While crop vegetation 10 m distant from sunflowers harbored significantly fewer beneficial insects, this difference in occurrence was not seen in crop vegetation 1 m distant from sunflowers. Our results indicate that sunflowers indeed attract and play host to numerous beneficial insects suggesting that sunflower plantings within rows of vegetable crops may indeed be an effective way to attract beneficial insects into cropped fields. However, further study is required to fully describe the distances key beneficial insects move from sunflowers and the impact these beneficial insects have on crop pests.

Key Words: beneficial insects, sunflowers, insect diversity, intercropping, organic agriculture

RESUMEN

El girasol esta descrito en muchos folletos de extensión agrícola y otras publicaciones agrícolas como una planta excelente para atraer insectos benéficos, además de incluir insectos de importancia como los polinizadores. Nosotros realizamos un estudio por un periodo de dos años en varias granjas orgánicas en el condado de Alachua en Florida para determinar sí la presencia del girasol sembrado en hileras en un sistema policultural aumentaría la presencia y la abundancia de insectos benéficos en campos sembrados. La ocurencia de insectos benéficos fue mucho mayor en el girasol que en el cultivo en los bloques de control y en las plantas del cultivo sembradas a más de 10 m de distancia de las hileras de girasol. Aunque las plantas del cultivo sembradas 10 m del girasol fueron un refugio menos significativo para los insectos benéficos, esta diferencia no fue observada en plantas del cultivo sembradas a 1 m de distancia del girasol. Nuestros resultados indican que los girasoles en verdad atraen y juegan un papel como hospederos a un gran número de insectos benéficos y se sugiere que la siembra del girasol en hileras de cultivos vegetales en verdad pueden tener un efecto para atraer insectos benéficos dentro de los campos agrícolas. Sin embargo, se requiere estudios adicionales para determinar las distancias de las especies claves de insectos benéficos que se mueven del girasol al cultivo y el impacto que tienen estos insectos benéficos sobre las plagas en los cultivos.

Translation provided by the authors.

Insect predators and parasitoids of crop pests can be influenced to take up residence within cropping systems by providing habitat for them (Helenius 1998). Farm management to enhance the presence of beneficial insects refers to the establishment of food resources and habitat required by these species that increase and sustain their populations (Pickett & Bugg 1998). Pollinators and parasitoids can be attracted to cropped fields by including nectar producing flowering plants. For example the planting of sweet alyssum (*Lobularia maritime* Linnaeus) around cabbage fields is thought to increase longevity of parasitic wasps that are beneficial in reducing pest populations in the field (Johanowicz & Mitchell 2000). These natural enemies can be attracted to cropped areas and their numbers increased by including within-field habitat strips, select cover crops, and proper management of field margins, hedgerows, fencerows, windbreaks, irrigation and drainage ditches, and roadside margins. For example, several studies have found that sown weed strips within cropped areas increased natural enemy abundance and activity in crops by providing habitat for these enemies into and throughout the interior of the cropped fields. Additionally, rates of feeding of these natural enemies on pest insects were higher near the sown

weed strips (Nentwig 1998; Schoenig et al. 1998; Wratten et al. 1998).

Sunflowers (*Helianthus* spp.) are listed in many extension factsheets (Univ. of Florida Extension Circular 563, Univ. of Rhode Island Landscape Horticulture Factsheet, Univ. of Maine Coop Extension Bulletin # 7150) and other such publications (Long 1993; Starcher 1995; Turton 1998) as excellent plants to attract beneficial insects such as those known to be important pollinators (e.g., honey bees and other bee species) or known to prey upon or parasitize agricultural insect pests (e.g., lacewings, big eyed bugs, ladybird beetles, and numerous parasitoids). While informative, these particular extension publications are directed to the home gardener describing how to attract beneficial insects to their gardens. Therefore, we wanted to test the effectiveness of attracting beneficials with sunflower plantings in a commercial cropping system context.

We performed a 2-year study at a number of organic farms in Alachua County, Florida to determine if the presence of sunflower rows included in a polyculture system increased the occurrence and abundance of beneficial insects in cropped fields. In year one we compared the occurrence of both beneficial and pest insects on intercropped sunflowers to those occurring on paired crop vegetation in control plots. In year two we attempted to determine whether predatory insects attracted to the sunflower rows moved into adjacent crop vegetation by compared the occurrence of beneficial insects on sunflowers and crop vegetation adjacent to sunflower plantings (within 1 m) to those occurring on the same crop vegetation 10 m distant from sunflower rows.

Materials and Methods

Research Site Selection

With the help of the director of the Florida Organic Growers Association, Marty Mesh, growers were identified in North-central Florida during the fall of 2001 and permission was obtained to conduct research activities on their properties during the course of our 2-year study. All participating farms were under certified organic management as designated by the Florida Organic Growers Association (Florida Certified Organic Growers and Consumers, Inc., PO Box 12311, Gainesville, FL 32604) and most are now USDA Organic certified.

Sunflower Intercrop Strips

Four growers were asked to incorporate rows of multi-branched open-pollinating varieties of sunflowers into their cropped acreage at the earliest planting dates during their planting season spring-summer 2002 and 2003. A total of 16 ten-acre blocks were chosen for the study, 8 of which received sunflower row treatment while the other 8 served as controls within the 4 participating farms. On each farm one ten-acre block received a treatment of 1 row per acre, another ten-acre block received a treatment of 2 rows per acre and each was paired with a control block. Sunflower rows consisted of 1-m-wide rows of plants at a density of approximately 9 plants per square meter and were interspersed between, and parallel with, production rows (Fig. 1). Sunflower rows were maintained throughout the growing season as other crops were planted, harvested, and rotated through the acreage of each farm's production area. Treatment and control blocks were also paired by crop type, which included sweet corn, collards, tomatoes, okra, and watermelon. Treatment blocks were assigned different treatments during the second field season.

Insect Surveys

During growing season 2002, insects were sampled a minimum of 3 times in 10 randomly chosen 1-m^2 quadrats within sunflower rows consisting of the sunflowers and crop vegetation (directly adjacent to sunflowers). Insects were also sampled in 10 randomly chosen locations in control blocks of the paired crop vegetation. During 2003, insects were again sampled a minimum of 3 times in 10 randomly chosen 1-m^2 quadrats within sunflower rows, 10 quadrats in crop vegetation at 1 m, and 10 quadrats at 10 m distant from the sunflower rows. Insects were sampled by standard scouting techniques involving a sweep net and a beat cloth, as well as examination of each leaf and flower head occurring within each quadrant and counting the numbers of individuals found per m^2 of crop vegetation (after Morris 1960; Southwood 1978). Insects observed were identified to family level and relative abundances noted. For most of the insects sampled, identification to family was followed by a quick ID to genus or species level to determine if an insect was an actual crop pest, benign, or beneficial according to Henn et al. (1997) and the UF Coop. Ext. Service Insect Identification Sheets SPSET 5 (1997). Most of these IDs to genus were made in the field to reduce the cost associated with further taxonomy. In our record keeping, it was noted where a genus and or species occurred more frequently then a counterpart organism from the same family. Those records that are more accurate than family taxonomy are shown in the tables and their numbers are not combined with other members within the same family. The occurrence and number of individuals per m^2 beneficial and pest insects found upon sunflower plants and crop vegetation during the two growing periods was compared with a univariate analysis of variance (Zar 1999).

Fig. 1. Multi-branching sunflower varieties were planted at 1 or 2 rows per acre between vegetable rows to attract birds and beneficial insects into cropped fields. A row of sunflowers is shown here planted between rows of tomatoes.

Results

Beneficial Insects

Beneficial insects were attracted to sunflower plants by the time the plants reached 0.15 m in height. Beneficial insects observed on sunflowers and nearby crop vegetation (within 1 m of sunflowers) included arthropod predators, parasitic wasps, and important pollinators representing 30 different families (Table 1). The most commonly occurring beneficial insects observed on sunflowers were big-eyed bugs (*Geocoris* spp.), honeybees (*Apis mellifera*), green lynx spiders (*Peucetia viridans*), ants (Formicidae), and sphecid wasps (Sphecidae). The most commonly occurring beneficial insects observed on nearby crop vegetation were green lynx spiders (*Peucetia viridans*), lady beetles (Coccinellidae), big-eyed bugs (*Geocoris* spp.), predatory stink bugs (Pentatomidae), and assassin bugs (Reduviidae). The occurrence of beneficial insects was greater on sunflower than on crop vegetation in control blocks in 2002 ($F_{1,16}$ = 11.78, P = 0.003; Fig. 2) and crop vegetation greater than 10 m distant from sunflowers in 2003 ($F_{1,16}$ = 12.94, P = 0.002; Fig. 3). While crop vegetation 10 m distant from sunflowers harbored significantly fewer beneficial insects, this difference in occurrence in sunflower and crop vegetation was not seen in crop vegetation 1 m distant from sunflowers when this was assessed during the 2003 growing period ($F_{1,22}$ = 2.29, P = 0.144; Fig. 3).

Pest Insects

Pest insects representing 12 different arthropod families were found on sunflowers and nearby crop vegetation (Table 2). The most commonly occurring pest insects were green stink bugs (*Acrosternum hilare*), corn flea beetles (*Chaetocnema pulicaria*, Chrysomelidae) and imported cabbageworm larvae (*Pieris rapae*), respectively. The occurrence of pest insects on sunflower and crop vegetation in control plots did not differ in 2002 ($F_{1,16}$ = 0.12, P = 0.74; Fig. 4) but did differ in 2003 ($F_{1,16}$ = 14.7, P = 0.001; Fig. 5). Greater mean numbers of pest insects per meter

TABLE 1. BENEFICIAL INSECTS THAT WERE OBSERVED TO OCCUR IN RANDOMLY PLACED 1-M SCOUTING PLOTS ON SUNFLOWER AND NEARBY CROP VEGETATION (WITHIN 1 M OF SUNFLOWERS) DURING SPRING GROWING SEASONS 2002 AND 2003. BENEFICIAL INSECTS INCLUDED ARTHROPOD PREDATORS, PARASITIC WASPS, AND IMPORTANT POLLINATORS REPRESENTING 30 DIFFERENT FAMILIES.

Family	Common name	Benefit
Anthocoridae	Pirate Bugs	Predator
Apidae	Honey Bees	Pollinator
Asilidae	Robber Flies	Predator
Cantharidae	Soldier Beetles	Predator
Chrysididae	Cuckoo Wasps	Predator
Coccinellidae	Lady Beetles	Predator
Danaidae	Milkweed Butterflies	Pollinator
Dermaptera	Earwigs	Predator
Eulophidae	Eulophid Wasps	Parasite
Formicidae	Ants	Predator
Gelastocoridae	Big-eyed Bugs	Predator
Halictidae	Green Metallic Bees	Pollinator
Hesperiidae	Skippers	Pollinator
Ichneumonidae	Parasitic Wasps	Parasite
Lycaenidae	Gossamer-winged Butterflies	Pollinator
Mordellidae	Tumbling Flower Beetles	Predator
Mutillidae	Velvet-ants	Predator
Mymaridae	Mymarid Wasps	Parasite
Oxyopidae	Lynx Spiders	Predator
Papilionoidae	Swallowtail Butterflies	Pollinator
Pentatomidae	Predatory Stink Bugs	Predator
Plutellidae	Diamond-backed Moths	Pollinator
Reduviidae	Assassin Bugs	Predator
Scarabaeidae	Scarab Beetles	Predator
Sphecidae	Sphecid Wasps	Parasite
Tenebrionidae	Darkling Beetles	Predator
Thomisidae	Crab Spiders	Predator
Tiphiidae	Tiphiid Wasps	Parasite
Trichogrammatidae	Trichogrammatid Wasps	Parasite
Vespidae	Vespid Wasps	Parasite

were observed on sunflower vegetation than on crop vegetation greater than 10 m distant from sunflowers (2.5 individuals/m^2 vs. 0.2 individuals/m^2, respectively). This same difference was found

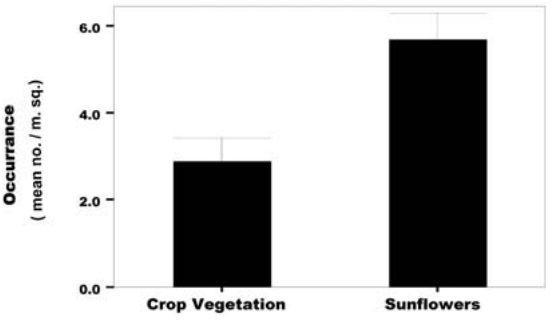

Fig. 2. Occurrence of beneficial insects was greater on sunflower vegetation than on crop vegetation during the 2002 growing season ($F_{1,16}$ = 11.78, P = 0.003). Error bars = 1 SE.

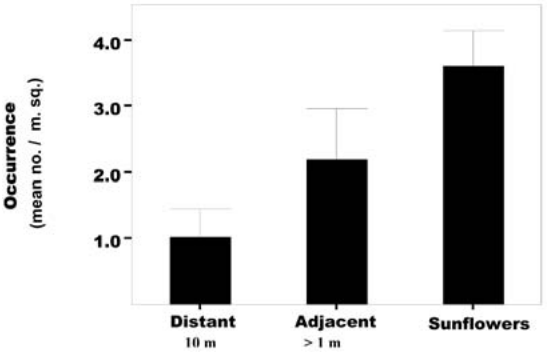

Fig. 3. The occurrence of beneficial insects was greater on sunflower vegetation than on crop vegetation more than 10 m distant from sunflowers in 2003 ($F_{1,16}$ = 12.94, p = 0.002). Occurrence of beneficial insects on crop vegetation 1 m distant from sunflowers did not significantly differ from that found on sunflower vegetation ($F_{1,22}$ = 2.29, P = 0.144). Error bars = 1 SE.

TABLE 2. PEST INSECTS THAT WERE OBSERVED TO OCCUR IN RANDOMLY PLACED 1-M SCOUTING PLOTS ON SUNFLOWER AND NEARBY CROP VEGETATION (WITHIN 1 M OF SUNFLOWERS) DURING SPRING GROWING SEASONS 2002 AND 2003. INSECTS OBSERVED ARE LISTED IN ORDER OF RELATIVE ABUNDANCE.

Family	Common name	Pest problem
Aphidae	Aphids	Disease transmission
Aleyrodidae	White flies	Disease transmission
Pentatomidae	Stinkbugs	Feeding damage
Chrysomelidae	Plant Beetles	Feeding damage
Lygidae	Plant bugs	Feeding damage
Coreidae	Plant bugs	Feeding damage
Cicadellidae	Leafhoppers	Disease transmission
Noctuidae	Armyworms	Feeding damage
Pieridae	Cabbageworms	Feeding damage
Plutellidae	Diamondback moths	Feeding damage
Sphingidae	Sphinx moths	Feeding damage

on crop vegetation within 1 m of sunflowers as well in 2003 (2.5 individuals/m^2 vs. 0.5 individuals/m^2, respectively, $F_{1,22} = 13.4$, $P = 0.001$; Fig. 5).

DISCUSSION

In this study we found that diversity and abundance of beneficial insects increased in crop vegetation directly adjacent to sunflower rows. Our scouting efforts revealed that sunflowers did indeed attract and play host to numerous beneficial insects as has been described in numerous publications. Sunflower plants were found to attract predaceous insects almost immediately after establishment when sunflower plants reached a minimum height of 6 inches. Parasitoids and pollinators were attracted as soon as these plants began to produce flowers. Some of the same beneficial insects were found also to occur on crop vegetation but in significantly lower numbers. It has been found in several studies that providing predator refugia within cropping systems via strip crops or uncultivated corridors can result in the migration of predatory insects into adjacent crops (see Johanowicz & Mitchell 2000; Mensah 1999; Nentwig 1998; Schoenig et al. 1998; Wratten et al. 1998; Rodenhouse et al. 1992). In the 2003 growing season, we modified the sampling methodology in an attempt to determine whether beneficial insects attracted to the sunflowers may have been moving out from the sunflowers into adjacent crop vegetation. Results indicated that crop vegetation within 1 m of sunflowers exhibited nearly the same abundance and diversity of beneficial insects as did the sunflowers them-

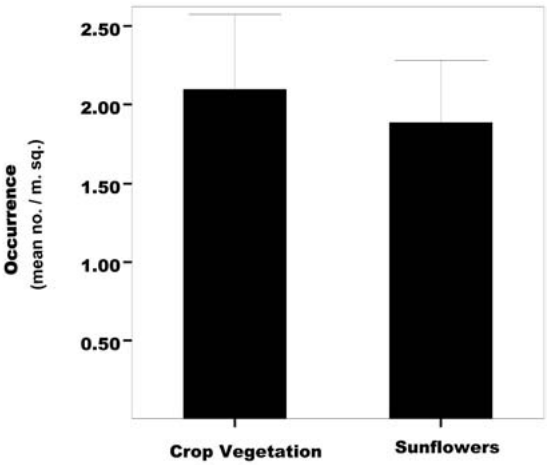

Fig. 4. Occurrence of pest insects on sunflower and crop vegetation in control plots did not differ in 2002 ($F_{1,16} = 0.12$, $P = 0.74$). Error bars = 1 SE.

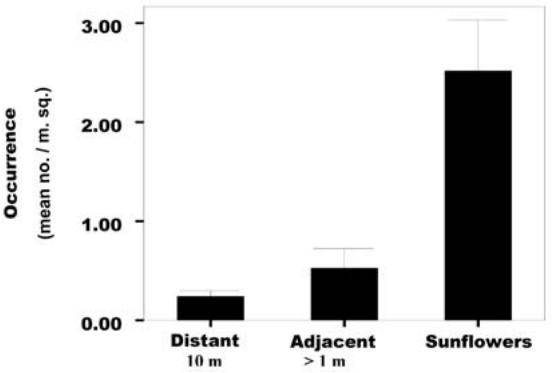

Fig. 5. Occurrence of pest insects on sunflower and crop vegetation greater than 10 m distant from sunflowers differed in 2003 ($F_{1,16} = 14.7$, $P = 0.001$). Greater mean numbers of pest insects per meter were observed on sunflower vegetation than on crop vegetation greater than 10 m distant from sunflowers (2.5 individuals/m^2 vs. 0.2 individuals/m^2, respectively). This same difference was found on crop vegetation within 1 m of sunflowers as well (2.5 individuals/m^2 vs. 0.5 individuals/m^2,respectively, $F_{1,22} = 13.4$, $P = 0.001$).

selves. However, crop vegetation 10 m distant from sunflowers harbored significantly fewer beneficial insects than did that within 1 m. Further study is required to fully describe the distances key beneficial insects move from sunflowers and the impact these beneficial insects have on crop pests. However, results of this study suggest that sunflower plantings within rows of vegetable crops may indeed be an effective way to attract beneficial insects into cropped fields.

Acknowledgments

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HOST SUITABILITY OF SELECTED *FICUS* SPECIES FOR *THRIPS PALMI* (THYSANOPTERA: THRIPIDAE)

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The melon thrips, *Thrips palmi* (Karny) (Thysanoptera: Thripidae), which is a pest on many ornamentals (Faust et al. 1992) and a known virus vector (Iwaki et al. 1984), probably originated in Southeast Asia (Girling et al. 1992). In the United States, it is reported from Florida and Hawaii, and since 1991, south Florida has experienced problems with *T. palmi* on potatoes, eggplant, bush beans, bell peppers, and yellow squash (Girling et al. 1992). It has a large host range of over 50 plant species (Dentener et al. 2002), of which eggplants and orchids are among the preferred hosts. Although not a problem on *Ficus* in Florida, *T. palmi* was reportedly intercepted in 1992 on *Ficus benjamina* cultivars from Florida in the Netherlands (Parrella & Mound 1998; Vierbergen 1996). Whether this was simply incidental, or whether *T. palmi* can use *Ficus* as a host plant for feeding and reproduction is unclear.

In this study we determine the suitability of *Ficus* cultivars as host plants for *T. palmi* compared to known host plants: *Dendrobium* orchids (Hata et al. 1991) and eggplant (Kitamura & Kawai, 1983), and record the presence/absence of *T. palmi* in a production *Ficus* nursery in Homestead, Florida, and surrounding areas. Experiments were conducted from October 1997 through March 1998 in a lab and an 8.08 hectare outdoor nursery planted with 4 *Ficus* spp. cultivars as rootstocks and 7 *Ficus* spp. in pots. The nursery was adjacent to a field planted with yellow squash from October to December 1997, and bush beans from January to February 1998. Weather parameters were recorded from the local Homestead weather station throughout the experiment.

To determine the host suitability, adult females of *T. palmi* were placed onto *Ficus benjamina* 'Monique', *Selanum melogena* (eggplant) and a *Dendrobium* orchid cultivar in no-choice tests and eclosion of larvae was monitored. Thrips used for these experiments were collected from cucumber and eggplant in southern Florida and reared on eggplant in a greenhouse. Individual plant sleeves (0.05 cm Reemay spun bound polyester; Kleen Test, Milwaukee, WI) were placed over 6 eggplant plants and 6 orchid flower spikes, with 2 sleeves fitted on to 2 plants or spikes containing no thrips (control) and 4 sleeves fitted on to 4 plants or spikes containing 10 adult female thrips. Each of 3 *Ficus* plants had 2 control sleeves with no thrips and 4 sleeves containing 10 adult female thrips per sleeve placed over individual stems. The mesh sleeves retained thrips on the plants although movement was not hindered. All adult thrips were counted and removed from each sleeve after 5 days, and eclosion of larvae was assessed by daily visual examination over the next 21 days. This experiment was replicated three times. Plants were kept in a lab maintained at 24°C with continuous fluorescent lighting. The average number of thrips larvae per plant/per day/plant species was compared across the three plant species by one-way ANOVA and Dunn's pairwise comparisons test at 0.05 level of significance.

The presence of thrips was recorded on 11 *Ficus* cultivars planted as rootstock or in pots in the outdoor nursery. Twenty *Ficus* plants were randomly selected and thrips were collected at weekly intervals by beating branches (3 strikes per branch; one branch per tree) over a white tray. In addition, twenty-five yellow sticky traps (SeaBright Laboratories, Emeryville, CA) (10.16 × 17.78 cm), set at 1 m above the ground, were placed throughout the nursery and replaced at weekly intervals over a 14-week period. The numbers and identities of thrips collected on each trap were recorded weekly.

The field adjacent to the *Ficus* nursery, as well as 10 fields containing bush beans, eggplant and squash within a 16 km radius of the nursery, were monitored weekly by visually inspecting 10 randomly selected plants within each field and recording the total count of *T. palmi*.

Thrips were slide-mounted and identified to species level with keys (Mound and Marullo 1996, Nakahara 1994, Bailey 1957) and deposited in the Bohart Museum of Entomology, UC Davis.

Ficus benjamina did not support reproduction of *T. palmi* ($H = 172.9$, $df = 2$, $P = <0.0001$) (Fig. 1). Eggplant (SEM = 4.43) supported significantly higher numbers of larvae than *Dendrobium* orchids (SEM = 1.87). Similarly, no live adult thrips were found on *Ficus*, whereas adult thrips were found alive on eggplant seedlings and orchid spikes (1-2 adults per sleeve/plant). *Thrips palmi* was not observed on the control eggplants, orchids or *Ficus*, although thrips could move through the mesh.

Numbers of *T. palmi* collected on sticky traps were low throughout the experiment, and only one adult was collected from the beating samples. Fifteen individuals of *T. palmi* were collected on cucumbers in a field approximately 16 km north of the nursery. *Thrips palmi* was not collected in weekly inspections of bush bean, eggplant, or squash fields.

Individuals of *T. palmi* on sticky traps in the nursery may have been dispersing adults from nearby vegetable fields. *Thrips palmi* is usually abundant on eggplant, bush beans, peppers, and potatoes from September to April (Frantz et al.

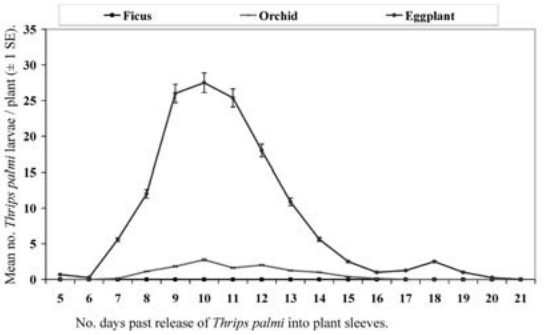

Fig. 1. The average number of larvae of *Thrips palmi* found per day/plant on 3 different host species. Numbers are based upon the average of three experiments for a total of 6 eggplants, 6 orchids, and 3 *Ficus* plants, with 6 sleeved replicates each. Standard error bars are shown for each plant type.

1995; Seal 1997). The low number of *T. palmi* collected throughout the experimental period may reflect low populations that only began to build up in vegetable fields late in the season. In fact, potato fields 12 km southeast of the nursery became heavily infested with *T. palmi* in late March 1998.

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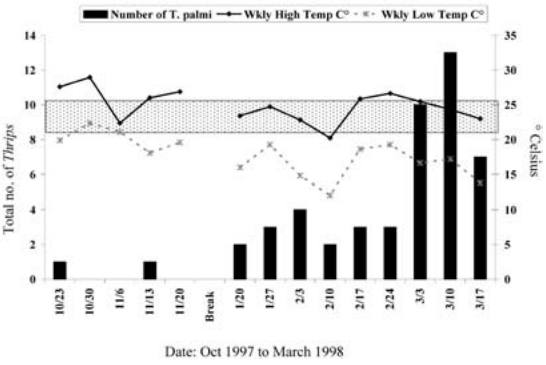

Fig. 2. Total number of *Thrips palmi* collected weekly on all 25 sticky traps at the *Ficus* nursery (bars) and temperature (solid line = high temp., dotted line = low temp.) taken from the weather station in Homestead, Florida, throughout the 14 weeks. The stippled area indicates the range of temperature that Teramoto et al. (1982) reported as the preferred egg-laying temperature for *Thrips palmi*. During the experiments, the average relative humidity ranged from 72-84% and the average precipitation from 0-11.91 cm per week. The average weekly low and high temperatures ranged from 12-22°C and 20-29°C, respectively.

Summary

Ficus was shown to be an unsuitable host for *T. palmi* because thrips confined to *Ficus benjamina* in a greenhouse produced no eggs, and no larvae, and only one adult of *T. palmi* was found on *Ficus* plants in the nursery, despite the presence of thrips on sticky cards. In contrast, eggs and larvae of *T. palmi* were detected on eggplant and orchid control plants in the greenhouse. Thus, *T. palmi* is likely a casual visitor when found on *Ficus*.

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NEW FLIGHT DISTANCE RECORDED FOR *COPTOTERMES FORMOSANUS* (ISOPTERA: RHINOTERMITIDAE)

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The Formosan subterranean termite (FST), *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), was first introduced to New Orleans after World War II inside infested cargo returning from the Orient (La Fage 1987). For the past 60 years, they have spread throughout the New Orleans metro area, displaced native subterranean termite species, and significantly damaged buildings, trees, boats, and railroad ties in the process. To help combat the problem, the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) provided funding for treating buildings in a 50-block area of the French Quarter in New Orleans to determine if an area-wide subterranean termite control program is capable of reducing overall populations. Since 1998, populations have been reduced based on structural inspections, termite activity inside independent monitoring stations installed throughout the French Quarter, and the overall number of alates (winged reproductives) recovered from insect glue boards attached to streetlights throughout the French Quarter (Lax & Osbrink 2003). However, alates are still being captured in significant numbers inside selective areas of the French Quarter and along the borders of this treatment zone.

Each year during May and June, untold numbers of male and female alates disperse throughout the area in the early evening and tend to congregate around light sources when present. Information on how far they are capable of flying from a dispersal point was virtually unknown, especially in a large urban area. During field observations in early 2004, it appeared that FST alates were flying across the Mississippi River with the aid of prevailing winds and into the French Quarter. To establish if alates were dispersing into the treatment zone from bordering areas, alates were marked with fluorescent visible powders (Shannon Luminous Materials, Inc., Santa Ana, CA) during two dispersal flights on different evenings at a selected site of known termite activity across the Mississippi River, located directly to the southeast of the French Quarter. In cooperation with USDA-ARS, 445 rectangular (20.7 cm × 10.2 cm) glue boards (TRAPPER® LTD, Bell Laboratories, Inc., Madison, WI) were attached to streetlights along the Riverwalk and throughout the French Quarter to capture potentially marked alates. The glue boards were positioned on the streetlights just below the lantern. Weather conditions, including wind velocity and direction, were recorded each evening with a hand-held weather station (Kestrel® 4000, Nielsen-Kellerman, Boothwyn, PA). Alates were individually marked with a bright orange fluorescent powder with a hand-held commercial duster as they were flying in a north to northwest direction over the river. These alates were already in flight at the time of marking and their source could not be located. After marking, every glue board was removed and inspected with a UV black light. New glue boards were used for each dispersal flight event.

On 1 June 2004, approximately 50 FST alates were initially marked and a single alate was recovered across the River on a glue board 771 m away (Fig. 1). Then, on 7 June, approximately 50 alates were marked again and two alates were recovered on glue boards 866 m and 892 m away (Fig. 1). The wind direction on 1 and 7 June was from the south and southeast at an average speed of 0.93 m/sec and 0.83 m/sec, respectively. Previously, a wind speed at or below 1.0 m/sec was shown to be one of the most important microenvironmental factors involved in determining dispersal flight activity (Leong et al. 1983).

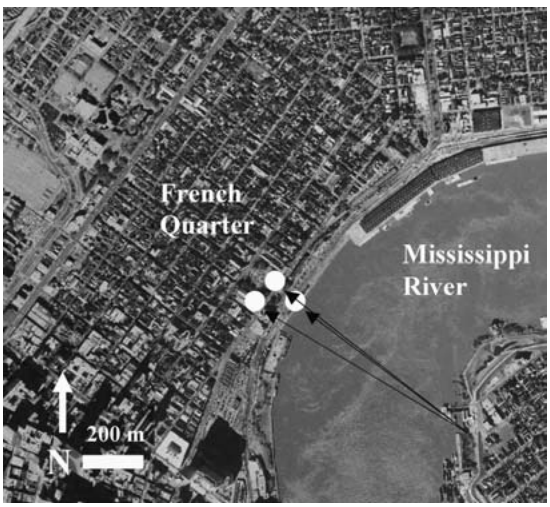

Fig. 1. Flight distances of three Formosan subterranean termite alates during dispersal flights across the Mississippi River in early June 2004 (Source of color-infrared photograph: National Aerial Photography Program, Jan. and Feb. 1998; courtesy of 3001-The Spatial Data Company).

Historically, the only documented standard for maximum FST dispersal was a horizontal flight distance of 460 m at 2.2 m/sec (Ikehara 1966). These alates were visually observed in a large courtyard-type area located in Japan. Other studies have shown that the FST is capable of infesting high-rise buildings (>40 m high) with the aid of ocean current winds (Su et al. 1989). However, the accepted horizontal dispersal distance for the FST has always been approximately 100 m (Higa & Tamashiro 1983). Our results show that the FST is capable of flying almost twice the standard maximum (460 m) distance. At the same time, alates were able to fly across the Mississippi River with the aid of low wind speeds (<1 m/sec). These data have shown how re-colonization is possible in a treatment zone, such as the French Quarter in New Orleans, particularly during FST dispersal flight activity. In addition, these data represent an important factor to consider when evaluating an area-wide termite treatment project.

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Summary

Results from two separate mark-recapture trials revealed that Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), alates are capable of flying nearly one kilometer across the Mississippi River and into the historic French Quarter. This is the first documented mark-recapture study with alates on this scale, and our results represent a new *C. formosanus* flight distance record.

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FLIGHT ACTIVITY OF TROPICAL SOD WEBWORMS (LEPIDOPTERA: PYRALIDAE)

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Lepidopterous larvae have long been recognized as major pests of Florida turf. Among these pests, the tropical sod webworm, *Herpetogramma phaeopteralis* Guenee is considered to be most damaging. This species has a wide tropical distribution and occurs along much of the Gulf Coast of the United States (Kerr 1955). All major southern turfgrasses in Florida are subject annually to potential damage by tropical sod webworms (TSW). Widespread damage can occur on virtually all types of turf areas, but infestation levels and the resulting damage are usually greatest on high-maintenance turf areas (Reinert 1983).

Webworms have been the target of extensive chemical control programs due to their widespread damage on golf courses, private lawns, and other turf areas in Florida and other southeastern states (Reinert 1973). Numerous studies have been published on the chemical control of sod webworms in Florida. However, in spite of the economic importance of TSW, only two studies have been published on the biology of this pest. Kerr (1955) describes some of the basic biology of TSW and Reinert & Busey (1983) note the resistance of bermudagrass selections to TSW. With the exception of these two studies, little is known of the actual biology of this important pest. The objective of this study was to determine the flight activity of TSW.

Seasonal flight activity of TSW was measured with a large, walk-in black light trap. This trap measured 2 m × 2 m × 2.5 m high and was made of wood with screened sides. On the top was a 15 watt black light with funnel through which insects fell into the trap below. The trap was located on the Everglades Research and Education Center (Univ. of Florida/IFAS), Belle Glade, Florida in an area composed of mixed vegetation (grasses, weeds, trees). The trap was used only one night per week in order to prevent possible depletion of local populations of TSW around the trap. Trapping was conducted for two years from June 2001 to June 2003. After collection, adult TSW were taken to the laboratory for positive identification and sex determination. In order to determine possible seasonal differences in flight activity, samples from 3 month periods were pooled. For the purposes of this paper, winter is defined as December, January, and February, spring is March, April, and May, summer is June, July, and August, and fall is September, October, and November. These definitions correspond to seasonal definitions for the North Temperate Zone (Guralnik 1982). Mean differences in TSW adults caught in the light trap between seasons was determined by using a Least Significant Difference (LSD) test (SAS 1996).

The distance flown by adult TSW when disturbed was determined in field tests at the Everglades Research and Education Center (EREC) during June-July, 2003, on four different days (n = 15 TSW adults recorded per day). All 60 observations were conducted during afternoons when temperatures were warm and winds mild, which is representative of southern Florida weather conditions during the summer. Observations were made by a person walking across a mowed grassy area of mixed species until a TSW appearing moth flew up. The location from which the moth flew was marked by dropping a ball and the moth was visually followed until it settled. Thereafter, the moth was caught in a fine mesh net as it flew up from its new location. Wind speed and air temperature at 1.5 m high were recorded and the moth was taken to the laboratory for identification and sex determination (Kerr 1955) via microscope. A t-test (SAS 1996) was used to compare the distance flown of males versus females of TSW. Also, linear correlation of flight distance versus air temperature and wind speed was performed (SAS 1996).

An additional test was conducted to determine if adults had a preference to reside in grasses of different heights. The test was conducted at the EREC in grassy areas of mixed species. Five pairs of plots were located in various areas of the EREC. Each plot was 10 m by 10 m and located 5 m away from its paired plot and appeared similar to its paired plot i.e., plant species, shade, etc. During October, 2003, portions of the EREC were mowed on different days, leaving one plot unmowed (tall grass) and one plot mowed (short grass). Samples were taken 24 h after mowing to allow time for disturbed TSW adults to settle into plots. Each pair of plots was sampled during the afternoon and at the same time to insure that light, wind, etc. would be the same between the two adjacent plots. One random sample of grass height was measured in each plot. TSW adults were sampled in each plot in five parallel transects evenly spaced through each plot. Twenty sweeps with a sweep net (38 cm diameter) were taken per transect. Each sweep consisted of a 180° sweep with each forward step. Mean differences in grass height and TSW adults/100 sweeps between tall versus short grass plots were compared by using t-tests (SAS 1996).

TABLE 1. TROPICAL SOD WEBWORM ADULTS CAUGHT IN A BLACKLIGHT TRAP DURING 2001 TO 2003.

Season	Mean[a]	SD	Range	% Female
Fall	70.5 a	125.8	3-476	69.5
Summer	16.6 b	23.0	1-99	59.6
Spring	13.2 b	42.5	0-205	65.3
Winter	9.8 b	23.3	0-110	66.7

[a]Means followed by the same letter are not significantly different (alpha = 0.05) based on the LSD test (SAS 1996).

Tropical sod webworm adults were active throughout the year in southern Florida (Table 1). Fewest adults were caught in the winter probably due to lower populations and/or cooler temperatures restricting flight at night into the light trap. Kerr (1955) noted that TSW adults became inactive at 14°C,which is within the range of night temperatures which may occur in southern Florida during the winter. Though not significantly different, more adults were caught during the spring and summer than during the winter. However, the fall clearly was the season of greatest adult catches, being more than winter, spring, and summer catches combined. Kerr (1955) reported that one of the largest outbreaks of TSW in Florida history occurred during the fall of 1953. He also noted the peak of adult emergence was in October and November in northern Florida. Reinert (1983) noted that TSW populations are present throughout the year in Florida, but most damage is incurred in late summer and fall. Our data are consistent with these earlier observations that although TSW populations are present year round, most damage is expected in the fall.

In the flight distance study, the sex ratio of males to female adults closely approximated 1/1 on each of the four days with the total number of males versus females being 30 to 30. The exact 1 to 1 sex ratio in total adults studied occurred by chance since adults were sexed only after being caught. A *t*-test showed that there was no significant difference (t = -0.52, 58 *df*, P = 0.61) between sexes in distance flown during the four days. Hence, data from the two sexes were pooled and an adult TSW irrespective of sex was shown to fly an average distance of 1.7 m ± 1.1 SD during our tests. The average temperature during the flight tests ranged from 31.2 to 37.6°C/day. No significant correlation (r = 0.20, P > 0.05) was found between temperature and flight distance as expected since all temperatures were very warm for flight activity with only a small temperature range in the observations. Wind speed (km/h) was more variable than temperature, ranging from an average 0.1 km/h on a very calm day to 1.6 km/h on a slightly windy day. A significant positive correlation (r = 0.40, P < 0.05) was found between wind speed and flight distance, which simply reflects adults being carried farther when flying under windier conditions. Kerr (1955) reported that TSW flight was relatively weak during the day and disturbed moths settled quickly, but data were not provided. Our data are essentially in agreement with Kerr's earlier observations.

In the study to measure if grass height influenced adult residence, the height of the grass in the unmowed plots averaged 14.6 cm ± 2.1 SD versus 7.2 cm ± 0.8 SD in the mowed plots. These means were significantly different (t = 6.1, 8 *df*, P < 0.05) as expected. The number of adult TSW caught in sweep net samples averaged 16.2 ± 10.1 SD in the unmowed plots versus 0.2 ± 0.4 SD in mowed plots. Again, these means were significantly different (t = 3.6, 8 *df*, P < 0.05). These latter data show that TSW were 81 times more likely to reside in tall grass versus short grass during daylight hours. Kerr (1955) noted that TSW adults rested in shrubbery around lawns during the day. Similarly, Reinert (1982) noted that TSW adults hide in tall grass, but like Kerr (1955), data were not supplied for the field observations. Our data corroborate these earlier studies showing that adult TSW have a high preference to reside in taller grass than adjacent shorter grass during daylight hours. In turf, sanitation involves practices to avoid introducing insects or mites into noninfested sites, as well as cleanup of debris that serves as hiding or overwintering sites for pests (Potter 1998). Our data suggest that reduction of taller vegetation such as grass and shrubs adjacent to turf and/or insecticidal treatment of taller vegetation adjacent to turf may be useful in reducing TSW infestations.

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SUMMARY

Flight activity of tropical sod webworms occurred throughout the year in southern Florida with most flight activity in the fall. Adults flew short distances when disturbed during the day and showed a high preference to reside in tall grass versus short grass during the day.

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HERBIVORES IN THAILAND ON *RHODOMYRTUS TOMENTOSA* (MYRTACEAE), AN INVASIVE WEED IN FLORIDA

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Downy rose myrtle, *Rhodomyrtus tomentosa* (Aiton) Hassk. (Myrtaceae), is an evergreen shrub native to Southeast Asia including Thailand (Verheij & Coronel 1992). It was introduced to the United States as an ornamental and is now invading native plant communities in Florida (Langeland & Craddock-Burks 1998). A preliminary survey of herbivores attacking this plant in Thailand was conducted from April 2001 to May 2002 to assemble data on their distribution, biology, and potential as biological control agents.

More than 60 field sites with *R. tomentosa* were visited, resulting in 43 collections and observations of insects and damage. Live immature insects were taken to the Department of Agriculture (DOA), Thailand, for rearing to their adult stage on nursery stock of *R. tomentosa*. Voucher specimens of the insects are lodged in the DOA insect collection, Bangkok, and at the USDA-ARS, Systematics Entomology Laboratory, Beltsville, MD. We used sequence data D2 expansion domain of the 28S rRNA to characterize morphological similar insects that were reared from hosts other than *R. tomentosa.* The methods are those described by DeBarro et al. (2000). Information is presented below on the species that were most common in our surveys.

In Thailand *R. tomentosa* occurs most frequently in coastal sandy soils on both coasts of the southern Peninsula, extending around to Trat Province and Klong Yai District in the east. We measured soil pH at several sites and found that it ranged from 4.0 to 10.0 with a mean of 5.8. The soils were mostly acidic except for two sites in Chumphon Province.

Two species of weevils *Sternuchopsis patrulis* (Faust) (= *Alcidodes patrulis*) and *Hypolixus truncatulus* (Fabricius) were collected from *R. tomentosa* at sites in southern Thailand near Nakhon Si Thammarat (NST). Weevils were observed on flushes of new growth causing stem damage resulting in death of growing tips. Eggs and larvae of these species have not been positively identified. *Sternuchopsis frenatus* (Feisthamel) (= *Alciodes frenatus*) was reported damaging leaf midribs and boring twigs of teak, *Tectona grandis* Teck (Verbenaceae) in Thailand (Hutacharern and Tubtim 1995).

A unknown species of thrips (Thysanoptera: Thripidae) was collected from flowers of *R. tomentosa* at sites in Surat Thani and NST. The species is similar to *Thrips coloratus* Schmutz. However females of the rhodomyrtus thrips are strikingly different as they have very long ovipositors. This may be a new species, possibly specific to *R. tomentosa* (L. Mound, pers. comm. Canberra, Australia).

Carea varipes Walker (Lepidoptera: Noctuidae) was not common, but this moth was collected at widely separated sites in Trat and NST. Larvae are large and obvious leaf feeders but have not been observed in large numbers. Pupation occurs in rolled leaves or between touching leaves. *Carea varipes* also has been recorded from Hong Kong, also on *R. tomentosa* (Mohn 2002).

Larvae in the genus *Agriothera* (Lepidoptera: Roeslerstamiidae) were found boring and feeding inside young flower buds and young fruit. This insect was the most common in our surveys and often found in large numbers. It is widely distributed, being collected from Chantaburi, Trat, Surat Thani, NST, Songkhla, and Trang provinces. The full grown larva is about 6-7 mm long, head pale, body creamy white with a red stripe on each abdominal segment. The adult moth is tiny, having brown fore wings with yellow bands at the posterior margins. Adults and larvae used in the identification came from different sites, so it is possible that more than one species is involved. Very similar but unidentified species of Lepidoptera larvae were collected attacking rose apple, *Syzygium jambos* (L.) Alston (Myrtaceae). Sequencing of the D2 gene showed around 60 base pair differences between this insect and the *Agriothera* sp., indicating it is not the same species.

Pingasa chlora (Stoll) (Lepidoptera: Geometridae) was found on *R. tomentosa* in Trat and NST. Young larvae bore inside folds and feed on young shoots and young flowers. Large larvae feed on young flushes of *R. tomentosa*. Head and body are pale green covered with short dense white hairs, with a spiracular line and oblique lateral streaks of each segment. *Pingasa chlora* is known as a pest of rambutan, *Nepthelium lappaceum* L. (Sapindaceae) and litchi, *Litchi chinensis* Sonn. Mill. (Sapindaceae) (Kuroko & Lewvanich 1993).

Trabala vishnou (Lefroy) (Lepidoptera: Lasiocampidae) is distributed widely in Thailand but was found on *R. tomentosa* only at one site in Bangkok. The female moth lays eggs in masses covered with anal tufts. Newly hatched larvae are gregarious; the body is yellow with black stripes, and the last instar larva is about 6 cm long. Wingspan of the adult is about 5 cm. The body and wing coloration of males is pale green, and yellow in females. Larvae feed on many fruit crop plants, such as rose apple, *S. jambos*; sapodilla plum, *Manilkara zapota* L. (Sapotaceae); Rangoon creeper, *Quisqualis indica* L. (Combretaceae), and others (Kuroko and Lewvanich 1993).

Lepidopteran larvae of a tortricid species were found feeding on young shoots of *R. tomentosa*. Larvae clumped leaves together to form shelters in which they fed. The moths are about 2-2.5 cm long, with bell-shaped wings when resting. It was found only in the south in NST and Surat Thani.

Larvae of *Hyposidra infixaria* Walk (Lepidoptera: Geometridae) cause minor damage to leaves of *R. tomentosa*. This moth was found at just one site in Trat province. Specimens in the DOA Insect Collection, Bangkok, have been collected from castor bean, *Ricinus communis* L. (Euphorbiaceae) and pomegranate, *Punica granatum* L. (Punicaceae).

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Summary

Rhodomyrtus tomentosa is a perennial shrub of Asian origin, which is becoming an increasingly serious invader of native plant communities in Florida. Based on a one-year survey of herbivores of this plant in Thailand, a suite of herbivorous insects was collected, including leaf and flower feeders, and stem and fruit borers. Six species, including two moths, *C. varipes* and *Agriothera* sp., an undescribed thrips, and two weevils, *S. patrulis* and *H. truncatulus*, show some traits of narrow host specifity and are recommended for further study as biological control agents.

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BEHAVIORAL ACTIVITY OF *ANISOMORPHA BUPRESTOIDES* POSSIBLY ASSOCIATED WITH HURRICANE CHARLEY (PHASMATODEA: PHASMATIDAE)

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On August 13, 2004, Hurricane Charley was making its way northeast through Central Florida. As the storm approached, I observed a large aggregation of two-lined walking sticks, *Anisomorpha buprestoides* (Stoll). I conservatively estimate there were several hundred pairs in the immediate vicinity, mostly of the Ocala color variant as described by Hetrick (1949). The habitat is located in North Central Lake County on land contiguous with the Ocala National Forest. The habitat is typical Florida scrub consisting of turkey oak (*Quercus laevis*), Chapman's oak (*Q. chapmanii*), sand live oak (*Q. geminata*), crooked wood (*Lyonia ferruginea*), scrub pawpaw (*Asimina obovata*), and palmetto (*Serenoa repens*). As is typical of *A. buprestoides*, the walking sticks were resting during the daylight hours on palmetto leaves. The time was 7-7:30 PM, about 45 minutes before sunset. The air was particularly calm as the outer edges of Hurricane Charley approached.

Then, as if some invisible signal had been sent, walking sticks began vibrating their legs against the palmetto leaves. Only the paired males exhibited this behavior. Clark (1974) reported that an *A. buprestoides* male may attach to the back of a female for up to three weeks. I noted that the paired females and the bachelor males did not drum their legs. I was unable to find any single females to report. It seemed that most, if not all, the paired males were drumming primarily with their prothoracic legs, but they did use all six of their legs as well. Due to the numbers involved, it sounded like a group of snare drums being struck with wire whisks. They continued drumming for no more than two minutes. The females remained motionless during this activity. Several tussles occurred between the bachelor males and they fell from the palmettos. Bachelor aggression may not be related to the drumming at all because bachelor aggression behavior has been observed before by Gunning (1987).

After two minutes, a few males continued as if they were 'finishing up,' but there were no more outbursts of drumming among the pairs. Within 10-15 minutes of finishing, the first rains of Hurricane Charley began to fall on the area. I've observed this large aggregation many times, before and after normal summer storms, and have never seen this behavior. It does not appear that the drumming behavior has been reported in the literature, although one of the anonymous reviewers of this paper also has seen the behavior.

One possible initiating cause for the drumming is the dropping atmospheric pressure associated with the oncoming hurricane. Although I didn't measure the pressure at the time, the NOAA reported a barometric pressure of 965mb or 28.5 inches as the eye passed through this area. A reasonable estimate would be 29.5 inches at the edge of the storm. Another explanation is that the drumming was merely coincidental to the hurricane. Only further observations of the drumming behavior may identify the cause.

I later attempted to stimulate the drumming response by vibrating a handful of thin plastic straps near the aggregation. This was unsuccessful. I did, however, succeed in receiving a dose of *A. buprestoides* defensive spray.

Speculating on the purpose of the drumming is difficult until further observations are made. If the drumming is territorial or mating related, this event would represent an interesting note on simultaneous behavior in *buprestoides* aggregations.

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SUMMARY

A large aggregation of *Anisomorpha buprestoides* exhibited synchronous 'drumming' of their legs prior to the onset of Hurricane Charley.

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RE-CONFIRMING HOST SPECIFICITY OF THE FIRE ANT DECAPITATING FLY *PSEUDACTEON CURVATUS* (DIPTERA: PHORIDAE) AFTER FIELD RELEASE IN FLORIDA

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Critics of biological control programs have argued that there is a lack of post-release monitoring on nontarget effects arising from released exotic insects. Howarth (1991) stated that negative environmental impacts of biological control introductions have not been well documented. Similarly, others have complained that releases of nonindigenous species on target organisms have led to reduction in populations of nontarget species due to inappropriate protocols on host specificity of these nonindigenous species (Barron et al. 2003; Civeyrel & Simberloff 1996; Hopper 2001; Howarth 1991; Secord & Kareiva 1996; Simberloff & Stiling 1996a, b). However, in spite of these criticisms the biocontrol community appears to have a good record of environmental safety (Lindgren 2003; McEvoy et al. 1991). Similarly, Pemberton (2000) analyzed works dealing with 117 natural enemies of 55 weed species and found that only 1 natural enemy completes development in a nontarget plant. A significant problem appears to be that biocontrol practicioners have not always done an adequate job of documenting the post establishment host specificity of organisms that they release.

However, this problem is beginning to be rectified. For example, post-release monitoring has been done for releases of the chrysomelid beetle *Galerucella calmariensis* on purple loosestrife *Lythrum salicaria* (in Michigan: Landis et al. 2003; in Canada: Lindgren 2003; in Oregon: Schooler et al. 2003), the fungal pathogen *Neozygites floridana* on the cassava green mite *Mononychellus tanajoa* in West Africa (Hountondji et al. 2002), the parasitoid wasp *Trichogramma brassicae* on the European corn borer *Ostrinia nubilalis* in Switzerland (Kuske et al. 2003), a South American mirid *Eccritotarsus catarinensis* on the waterhyacinth *Eichhornia crassipes* in South Africa (Coetzee et al. 2003), the rubber vine moth *Euclasta whalleyi* on the rubber vine *Cryptostegia grandiflora* in Australia (Cruttwell McFadyen et al. 2002), the tephritid fly *Acinia picturata* on the exotic weed *Pluchea odorata* in Hawaii (Alyokhin et al. 2001), and the melaleuca weevil *Oxyops vitiosa* on *Melaleuca quinquenervia* in Florida (Paul Pratt, pers. comm.). All of these studies have found minimal or no non-target effects.

The host ranges of phorid decapitating flies in the genus *Pseudacteon* have been studied extensively prior to field releases as self sustaining biocontrol agents of imported fire ants (Folgarait et al. 2002; Gilbert & Morrison 1997; Morrison & Gilbert 1999; Porter 1998, 2000; Porter & Alonso 1999; Porter & Gilbert 2004; Vazquez et al. 2004). *Pseudacteon tricuspis* Borgmeier flies were successfully established on red imported fire ant (*Solenopsis invicta* Buren) populations at eight sites in North Florida (1997-1999: Porter et al. 2004). In the fall of 2003, host specificity of *P. tricuspis* was tested in the field and results demonstrated that these phorid flies had no attraction to non-host organisms including native fire ants (Morrison & Porter 2004). These results are consistent with predictions from quarantine laboratory tests (Gilbert & Morrison 1997; Porter & Alonso 1999) and field tests in South America (Porter 1998) prior to its release in the United States.

A second phorid fly species, *Pseudacteon curvatus* Borgmeier from Formosa, Argentina, was released in Florida to control populations of red imported fire ants (Vazquez et al. 2005). The *P. curvatus* flies were collected attacking *S. invicta* fire ants 35 km NW of Formosa, Argentina by SDP and J. A. Briano (October 2001). *Pseudacteon curvatus* is a small decapitating fly that normally parasitizes small red imported fire ant workers. Quarantine-based host specificity testing predicted that this Formosa biotype was highly host-specific to *S. invicta* and that nontarget effects to the native fire ants, *Solenopsis geminata* (Fab.) and *Solenopsis xyloni* McCook would be minimal to non-existent (Vazquez et al. 2004). *Pseudacteon curvatus* was first successfully released and established in Florida at Whitehurst Farm, 15 mi SW of Gainesville, FL in the spring of 2003 (Vazquez et al. 2005). The objective of this paper is to document the host specificity of established field populations of the Formosa biotype of *P. curvatus*.

Field observations of host specificity were made in October 2003 between 1300 and 1530 EST, when the temperatures were >24°C. We tested the attraction of established *P. curvatus* flies to 15 species of non-*Solenopsis* ants: *Aphaenogaster miamiana* Wheeler (0.8-0.9 mm head width, 0.2 g of workers used), *Aphaenogaster* c.f.

carolinensis Wheeler (0.7 mm, 0.7 g), *Camponotus floridanus* (Buckley) (2.2 mm, 4 g), *Camponotus impressus* (Roger) (0.7-0.8 mm, 0.6 g), *Crematogaster minutissima* Mayr (0.6 mm, 2 g), *Crematogaster pilosa* Emery (0.7-0.9 mm, 2 g), *Cyphomyrmex rimosus* (Spinola) (0.6 mm, 0.2 g), *Dorymyrmex bureni* (Trager) (0.7-0.9 mm, 0.3 g), *Forelius pruinosus* (Roger) (0.5 mm, 0.3 g), *Linepithema humile* Mayr (0.6 mm, 2 g), *Odontomachus brunneus* (Patton) (1.8 mm, 0.4 g), *Pheidole dentata* Mayr (0.6 mm minors, 1.2 mm majors, 0.6 g), *Pogonomyrmex badius* (Latreille) (2.1-2.4 mm, 1.4 g), *Pseudomyrmex pallidus* (F. Smith) (0.6 mm, 0.1 g), *Trachymyrmex septentrionalis* (McCook) (0.8-1.0 mm, 0.2 g), and 6 colonies of *S. invicta* (0.6-1.4 mm, 1.5 g) workers. In the laboratory, *P. curvatus* successfully parasitizes *Solenopsis* ants with head widths of 0.6-1.1 mm (median of 0.74 mm; Morrison et al. 1997 and SDP unpublished data). All ant species used in these tests were collected near Gainesville, Florida (September 2003).

Trays with the 15 non-*Solenopsis* ants were set out first. Trays were 40 × 26 × 8 cm in size, with the inside coated in Fluon (AGC Chemicals Americas Inc., Bayonne, NJ), and contained only one species of ant. We conducted field observations in a 10 × 10 m shady area in one of Whitehurst Farm's well managed pastures (220 ha). The non-*Solenopsis* ants were then removed after 30 min and replaced with the 6 trays of *S. invicta*. At the conclusion of 30 min, the *S. invicta* trays were replaced with the 15 trays of non-*Solenopsis* ants to determine if the flies originally attracted from the *S. invicta* trials would exploit the other genera in the absence of its primary host (no-choice). Established *P. curvatus* flies observed hovering in attack mode over each tray were collected at 5 min intervals for 30 min. All flies were aspirated with an Allen-type double chamber aspirator and retained in vials until the conclusion of each 30 min trial when they were identified to species using a hand lens. Aspiration of flies normally does not change attack behavior once flies are released (Morrison et al. 1997). Therefore, the released flies readily resumed attacking red imported fire ants. Collection and identification for presence of *P. curvatus* flies was necessary since *P. tricuspis* flies were present at the study site from a release in Gainesville, Florida, in the summer and fall of 1997 (Porter et al. 2004). Flies captured during observations were then released prior to setting up additional trays. These methods were replicated on two consecutive days.

Further tests of *P. curvatus* host specificity were conducted with five trays of *S. invicta* and five trays of the native fire ant, *S. geminata*. Each tray contained 2 g of workers and 2 g of brood. As described above, the five trays of *S. geminata* were set out first for 30 min. *Solenopsis geminata* trays were then removed and replaced with the *S. invicta* trays and these trays were observed for 30 min. At the conclusion of 30 min, the five trays of *S. invicta* were replaced again with the five trays of *S. geminata* for an additional 30 min. Attacking flies were collected at 5 min intervals as described above. These methods were replicated on two days (five days apart) at the same site mentioned above.

The *P. curvatus* flies were not attracted to any of the 15 non-*Solenopsis* genera during the sequential series trials over the two days (Table 1). However, the flies were readily attracted to *S. invicta* (99 on day 1 and 38 on day 2, Table 1). As is normal, these flies hovered above their host, oriented themselves to workers, and readily struck the thorax of workers in an attempt to oviposit in the ants. When the six *S. invicta* trays were removed and replaced again with the 15 trays of non-*Solenopsis* ants, *P. curvatus* flies were not observed hovering over any of the non-*Solenopsis* trays. *Pseudacteon curvatus* flies were present at all six *S. invicta* trays during the trials.

In the *S. invicta* versus *S. geminata* trials, *P. curvatus* flies were not observed hovering or attacking over *S. geminata* during the first day and only 2-4 flies were observed hovering on the second day (Table 1). Flies collected above the native fire ants generally hovered briefly without attacking. Only one fly attempted to oviposit, but it flew away immediately after without returning. In quarantine tests, this biotype would occasionally attack *S. geminata* workers but attacks were never successful (Vazquez et al. 2004). *Pseudacteon curvatus* flies were present at all five *S. invicta* trays during the first day and present at four of five trays on the second day. *Pseudacteon curvatus* flies were present at none of the five *S. geminata* trays during the first day and at 1 of 5 and 3 of 5 trays on the second day (Table 1).

Field-established *P. curvatus* individuals were attracted to *S. invicta* over *S. geminata* by a ratio of about 30 to 1 (119 to 4 total flies, Table 1). These results were better than results predicted from quarantine tests where *P. curvatus* hovered over *S. invicta* versus *S. geminata* at a ratio of 1.3 to 1 in no-choice tests (Vazquez et al. 2004). Perhaps this difference was because *P. curvatus* flies in the laboratory tests were confined in small test containers leading to higher rates of hovering. Furthermore, attacks on *S. geminata* were very rare to non-existant in the field confirming laboratory choice tests where attack rates were 16 times higher for females hovering over *S. invicta* than for flies hovering over *S. geminata* (7.02 ± 1.41 (mean ± SE) versus 0.44 ± 0.28 attacks/min, respectively; Vazquez et al. 2004). We demonstrated in quarantine tests (no-choice and choice) that the Formosa biotype of *P. curvatus* does not complete development in *S. geminata* (Vazquez et al. 2004).

Post-release populations of *P. curvatus* were not attracted to any of the 15 non-host ant genera. In host-specificity tests with a biotype from Las Flores, Argentina, *P. curvatus* hovered over most

TABLE 1. NUMBER OF *PSEUDACTEON CURVATUS* FLIES COLLECTED HOVERING IN ATTACK MODE OVER NON-HOST ANT SPECIES, NATIVE FIRE ANTS (*SOLENOPSIS GEMINATA*), AND RED IMPORTED FIRE ANTS (*SOLENOPSIS INVICTA*) DURING SEQUENTIAL SERIES OF FIELD TRIALS (SEE METHODS).

Ant species	Flies collected				Trays attacked
	0-10 min	11-20 min	21-30 min	Total	
S. invicta vs 15 non-host genera (day 1)					
All 15 genera	0	0	0	0	0/15
S. invicta	14	56	29	99	6/6
All 15 genera	0	0	0	0	0/15
S. invicta vs 15 non-host genera (day 2)					
All 15 genera	0	0	0	0	0/15
S. invicta	7	14	17	38	6/6
All 15 genera	0	0	0	0	0/15
S. invicta vs *S. geminata* (day 1)					
S. geminata	0	0	0	0	0/5
S. invicta	28	20	18	66	5/5
S. geminata	0	0	0	0	0/5
S. invicta vs *S. geminata* (day 2)					
S. geminata[a]	0	1	1	2	1/5
S. invicta	14	16	23	53	4/5
S. geminata[b]	1	3	0	4	3/5

[a]No oviposition attempts were observed.
[b]Only one oviposition attempt was observed.

of 19 non-host genera in quarantine conditions (Porter 2000); however, they generally hovered without attacking and no parasitism occurred in any of the 19 non-host genera (Porter 2000). Results from this study demonstrate that host specificity of *P. curvatus* is restricted to *S. invicta* and poses no realistic threat to the congener *S. geminata* or ants in other genera.

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SUMMARY

Post-release monitoring confirms that the Formosa biotype of *P. curvatus* is not attracted to non-*Solenopsis* ants. Flies were attracted to the native fire ant, *S. geminata*, at very low rates (<5% of that with *S. invicta*) but virtually no oviposition attempts were observed. Overall results were consistent with laboratory predictions except attraction rates to nontarget fire ants in the field were much lower than in small laboratory test chambers.

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BOOK REVIEWS

ADLER, P. H. D., D. C. CURRIE, AND D. M. WOOD. 2004. The Black Flies (Simuliidae) of North America. Comstock Publishing Associates, a division of Cornell Press; Ithaca, NY in association with The Royal Ontario Museum. 941 pp. ISBN 0-8014-2498-4. Hardback. $99.95.

Black fly larvae are a significant component of many running water communities and on land the adult biting females not only cause trauma and blood loss but also carry parasites and pathogens. Less studied is their role as food for insectivores such as spiders, birds and bats. Their role as pollinators is unproven although suspected because adult black flies feed on flower sugars for flight energy. Finally, although again unproven, the death of vast numbers of adults on land must transport some nutrients back to the terrestrial ecosystems, which in nutrient poor regions may be significant. These attributes of black flies have generated considerable research over the last 240 years. This book alone cites over 2200 references on taxonomy, biology, vector status, control and management, and provides a broad overview of these topics in the North American context with an emphasis on systematics and taxonomy. It discusses the 367 species' names for North American Simuliidae, of which 43 are proposed in this volume.

The lack of comprehensive knowledge of the phylogeny and systematics of this family has been a major hindrance both to identification and to the development of a clear phylogenetic context. The authors of this book recognized the confused state of our knowledge and took up the challenge for the North American fauna. The result is a remarkable and rigorous review of the history, biology, systematics, taxonomy and distribution of the family Simuliidae in North America that will be a standard reference for years to come.

The book is divided into four parts: Background, Biology, Economic Aspects and Systematics and Taxonomy. Part I (The Background) is 30 pages and three chapters. The Overview chapter gives a thumbnail review of black fly knowledge. The chapter on the History of Research is a fascinating review of the last 200 years of study of North American black flies with 32 photographs that put a face to a number of people who have contributed to the field. Prior to the publication of this book 324 formal species' names had been proposed for North American simuliids and this book adds 43 new species for a total 367 proposed names (with 120 of these accepted or placed as synonyms). The chapter on Techniques for Collection, Preparation and Curation provides clearly outlined methods for preserving and preparing specimens for use in morphological, cytological and molecular investigations.

Part II (Biology) comprises 63 pages and three chapters. The chapter on Structure and Function is a clearly illustrated description primarily of external morphology and its functional significance for all stages. Internal anatomy gets only a brief description without illustrations, which would have been a useful addition, and the authors note that studies of comparative internal anatomy are very limited but are needed to provide additional phylogenetic information. The chapter on Cytology describes the polytene chromosome structure in detail and the development of using the distinctive banding patterns as characters for elucidating taxonomy and systematics of black flies. The chapter on Behavior and Ecology provides both a concise overview of the ecology, behavior, parasites, and pathogens of simuliids, and an account of the taxa carried by simuliids to vertebrate hosts. Later in the book (Part IV) more specific data on all these subjects are provided for each species, making it an enormous resource of biological information along with references to primary sources.

Part III (Economic Aspects) comprises 24 pages and two chapters. The Social and Economic Impact chapter is an excellent overview of social and economic impacts of the biting females and the associated vectoring of parasites and pathogens to humans and animals. These include both behavioral and medical reactions in humans which seriously affect outdoor work and recreation. They note that the true impact of blood feeding and transmitted parasites on wild host populations is poorly known, but the pictures of blood-feeding flies on a loon and swarms of them over cattle suggest it is significant and needs evaluation. The chapter on Management is a concise and informative review of the history and development of control measures primarily in the 20th century both for larvae and for the protection of humans and animals from biting females. Some early control measures and their environmentally disastrous nature illustrate the desperation people felt when confronted by these biting pests.

Part IV, Systematics and Taxonomy, forms the bulk of the book with 728 pages and two chapters. The chapter Phylogenetics and Classification of Holarctic Black Flies is one of the most clearly written arguments for a phylogenetic classification I have read. They use 230 characters to classify the Holarctic taxa to the level of family, subfamily, tribe, genera, subgenera and species group. They recognize two subfamilies in North America, Parasimuliinae with one genus and Simuliinae with two tribes and 12 genera. Many of the genera recognized by European workers are considered synonyms of one of these genera or

reduced to subgenera or to species group. This welcome framework provides a workable phylogenetic system within which taxonomic relationships and associated biological characteristics can be easily visualized. The chapter called Synoptic List, Identification Keys and Taxonomic Accounts of North American Black Flies will be the main focus for most users of this book. It starts with a synoptic list of all proposed species' names and their status. This is followed by 64 pages of keys to all stages, then 204 pages of accounts of all 255 recognized species, and the remainder of the chapter is illustrations and distribution maps. The keys are well designed with some taxa appearing in more than one couplet to cover variants. External morphological characters are used first and polytene chromosome characters last if required. The accounts of species provide not only details of synonymy and brief synopses of taxonomy and biological characteristics but also key references to primary literature. These, combined with the review chapters, are a goldmine of information. There are 824 line-drawn illustrations and 18 photomicrographs along with 24 colored plates illustrating 18 species of adult female scutal patterns and 131 species of mature larvae in dorsal view. All illustrations have sharp definition and are very informative with color beautifully reproduced. The polytene chromosome characters are not provided here but ample references are provided. Each distribution map shows all of Canada and the USA with provinces, states and counties shown and each species is separately plotted. These are a goldmine of biogeographical information; for example, somewhat to my surprise they show that Alaska and Northwest Territories have a rich blackfly fauna whereas the south central regions are relatively impoverished.

This book is a superb basic reference on phylogeny, systematics, identification, and biology of the Simuliidae of North America. I strongly recommend this reasonably priced volume to anyone interested in black flies, medical entomology, stream ecology, biodiversity, or biogeography. It is simply a wonderful example of good, rigorous science. I acknowledge constructive suggestions that improved the clarity of the review by colleagues Roger Pickavance and Peter Scott.

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DACCORDI, M., AND P. M. GIACHINO [Eds.]. 2003. Results of the Zoological Missions to Australia of the Regional Museum of Natural Sciences of Turin, Italy. I. Monografie XXXV, Museo Regionale de Scienze Naturale Torino. 565 pp. ISBN 88-86041-49-7. Hardback. 40 Euros + postage from Museo Regionale di Scienze Naturali, Via Giolitti 36, 10123 Torino, Italy. Fax (011) 43207301.

It used to be during the 19th century and first six decades of the 20th century that European museums or scientific societies would organize collecting expeditions to remote corners of the world. Then, over years, would appear volumes of descriptions of new species, in most instances preceded by accounts of geography and geology. One well-known example is the long set of volumes called Biologia Centrali-Americana published in England between 1879 and 1907. Some of those volumes, even after more than a century remain the latest comprehensive studies of some insect families in Mexico and Central America. Other notable examples are volumes published on the fauna of the former Belgian Congo by the Institut National des Parcs Nationaux du Congo Belge.

Such expeditions and accounts therefrom have become rarer. Although there was a grandiose expedition (The Wallace Project) to Sulawesi (Indonesia) in 1985, marking the centenary of exploration in Indonesia by Alfred Russel Wallace, results were not published in a single set of volumes. The book before me is the result of Italian expeditions to Australia that extended from 1991 through 2002 with gaps. It was supported by personal funds of some researchers, by Accademia Nazionale dei Lincei of Rome (1996-2002), and by the Museo Regionale de Scienze Naturali of Turin (1998-1999). Of course the expedition established collaborative relationships with Australian institutions and researchers, but the Italian researchers have substantially advanced the progress of knowledge of the Australian invertebrate fauna. This appears to be the first volume of a set. Although most authors are Italian, they wrote all contributions in English, making the information much more available to Australian (and American) researchers. I congratulate them on their effort because English is at best a second language for almost all of them. This would not have happened in the early years of the 20th century when similar works appeared especially in French, German, and Italian.

This book begins with a 9-page preface concentrating on the environments where collections were made, and illustrated by color photographs. It describes places visited and collection methods. It emphasizes Australian studies as a means of understanding the Gondwanian linkages between Australia, southern Africa, and southern South America.

Groups of invertebrates dealt with in this book are oligochaete worms (one chapter), carabids (five chapters), aleocharine staphylinids (one chapter), cholevine leiodids (one chapter), tenebrionids (one chapter), scarabs in almost the broadest sense (one chapter), lucanids (one chapter), chrysomelids (four chapters), some sphecids and some eumenids (one chapter each). So the book is a "must have" for enthusiasts of carabids, chrysomelids, Australian invertebrates, and anyone who is digging for information on Gondwanian zoogeography. Others with systematic interests in the other groups documented most likely will be content with a photocopy of the chapter of special interest for personal study.

My special interests in the book were in a chapter by Pier Mauro Giachino, The genus *Pheropsophus* Solier, 1833 in Australia (Coleoptera: Carabidae), and in one by Roberto Pace, New or little known Aleocharinae from the Australian Region (Coleoptera: Staphylinidae). I was surprised to note that Giachino, who provided beautifully colored drawings of adults and a little information about habitats, does not acknowledge Terry Erwin's (1971) reclassification of Pheropsophina, in which only the Neotropical species are classified in *Pheropsophus*. I was not surprised by Pace's chapter, in which dozens of new species and some new genera are described, and a few are redescribed more completely than before, accompanied by line drawings, as one of a seemingly endless series of papers by this author dealing piecemeal with the world's huge aleocharine fauna. On a lighter note, in one of the chapters on chrysomelids, I was surprised to learn of the existence of a genus named *Faex* by the 19th-20th century taxonomist J. Weise. The Latin word *faex* is the singular of *faeces*—perhaps Weise was having a bad day when he chose that name.

An index to taxa included would have been a worthwhile addition. Perhaps a better marketing strategy would have been to wait until more chapters had been written, and then to organize them along classificatory lines so that there might be one volume on Hymenoptera, one on Diptera, one on Coleoptera, etc. Arguably, this might have promoted sales to taxonomists interested in one invertebrate order but not others. The purchase price is a bargain, especially compared with the price it might have commanded from a commercial publishing house, because it is beautifully produced, although the $U.S. has now (5 November 2004) reached an all-time low of 0.78 Euros.

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ERWIN, T. L. 1971. Notes and corrections to a reclassification of bombardier beetles (Carabidae, Brachinida). Quaest. Entomol. 7: 281.

HEMING, BRUCE S. 2003. Insect Development and Evolution. Cornell University Press, Sage House, 512 E. State St., Ithaca, NY. xv + 444 pp. Cloth Hardback. ISBN 0-8014-3933-7.

Insect Development and Evolution is an excellent resource and reference book for insect biologists and others conducting research with insects. Many scientists using insects as models in genetics and biological development do not have a formal background in entomology, and this book will be an invaluable source of fundamental information. The book is oversize, and the 400+ pages contain a vast amount of information. It grew out of the author's more than 30 years teaching of insect development.

The book comprises 13 chapters, as follows: The Male Reproductive System and Spermatogenesis; The Female Reproductive System and Oogenesis; Sperm Transfer, Allocation, and Use; Sex Determination; Parthenogenesis; Early Embryogenesis; Specification of the Body Plan in Insect Embryos; Organogenesis; Postembryonic Development and Life History; Molting and Metamorphosis; Specification of the Adult Plan; Hormones, Molting, and Metamorphosis; and Ontogeny and Hexapod Evolution.

There are many fascinating topics one could mention in this book, but I choose two that particularly interest me. The first has to do with the pupal stage in insects. The insect pupal stage is unique. Pupation has many of the characteristics of a second embryonic stage in midlife of the insect. The embryo in the egg develops into a larva that hatches, feeds, grows, and molts as it gets larger. Sometimes after only a few days of larval life, sometimes after weeks, it enters the (mostly) quiescent pupal stage during which larval tissues are nearly completely broken down and an adult body plan is fashioned. The adult usually looks quite different from the larval form, and has a different life history. How did the same organism evolve these two strange and wonderful lives? What forces acted during ancient insect evolution to create a complete metamorphosis through egg, larva, pupa, and adult life forms? Starting on Page 248 the author devotes 9 (oversize) pages to an evaluation and discussion of the many models that have been proposed to explain the evolution of complete metamorphosis.

I found Chapter 12 entitled Hormones, Molting, and Metamorphosis a very interesting chapter. Some might think that insects are too simple to have much in the way of hormonal controls. In truth, virtually every aspect of insect biology, including behavior, digestion, metabolism, excretion, reproduction, pheromone synthesis and secretion, and development is under some form of hormonal control. This chapter deals mainly with developmental aspects of hormones. The chapter, comprising 32 pages, is an intense lesson in insect development as influenced by hormones. The author starts with a delightful summary of work in the early decades of the 20th century that established hormonal control of molting and metamorphosis, leading to isolation and identification of a complex of hormones involved in molting and metamorphosis. As the author concludes near the end of the chapter, the story is already complex, but not yet complete. The ecdysteroids are known to act at the gene level, controlling transcription, but the mechanism of action of juvenile hormone in regulating the type of molt, for example, is still unknown. Although juvenile hormone seems to be unique to insects, many of the other hormones, including the ecdysteroids, belong to families of hormones known to be functional in vertebrates. Hormonal control of development and physiological function is clearly fundamental, evolved early, and much conserved throughout evolution.

There are many line drawings in the book, one or more on nearly every page. The drawings are detailed, sometimes complex, and sometimes a little small, requiring careful study to get the full meaning.

The book contains nearly 60 pages of references to the literature of insect biology and development, providing a guide into the primary literature. The book will be useful to teachers of insect development, and as Heming has done, can be used as a textbook for a one- or two-semester course in insect development. As scientific and textbooks go today, the price is very modest and should enable many graduate students to purchase the book as a resource book even if not used as a textbook. Overall, I think this is a very useful book for any scientist working with insects.

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