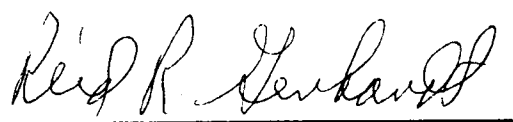


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REDESCRIPTION AND BIOLOGY OF Coccophagus lycimnia (WALKER),  
(HYMENOPTERA: APHELINIDAE)

A Thesis  
Presented for the  
Master of Science  
Degree  
The University of Tennessee, Knoxville

Mark A. Muegge

March 1988

#### DEDICATION

This thesis is dedicated to my parents, Richard and Barbra Muegge, to my sister Terry K. Muegge, and to my grandmother Kathrine A. Daily, for without their love, support, and encouragement this endeavor would not have been possible.

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## ABSTRACT

Basic biological research on systematics and life histories of predators and parasitoids is essential for successful implementation of an integrated pest control program. Coccophagus lycimnia (Walker) may prove to be a useful biocontrol agent of the brown soft scale Coccus hesperidum (L.); however, little of its biology is known. The objective of this study was to describe the immature stages of female C. lycimnia and determine the longevity, fecundity, and optimal host length for oviposition by adults. Additionally, adult C. lycimnia were redescribed to aid in species identification.

Brown soft scales were used as hosts for C. lycimnia. The scales were reared on watermelon, Citrullus vulgaris Schrader, to obtain large populations for subsequent testing. Bird's nest ferns, Asplenium nidus L., were used as hosts for the brown soft scale when conducting tests with C. lycimnia.

Previous descriptions of C. lycimnia and its synonyms were based primarily on differences in color. Since color variability of this species may have led to its many synonyms, a redescription of C. lycimnia was conducted. Measurements and descriptions of 160 characters were analyzed using correlation coefficients and coefficients of variation. Characters with low coefficients of variation

and high correlation coefficients were used as possible characters for species separation, since other species of Coccophagus were unavailable for comparison.

The optimum size of C. hesperidum for parasitism by C. lycimnia ranged between 1100 to 1500 $\mu$ m long. Parasitized scales continued to develop.

Mated females of C. lycimnia oviposited an average of six eggs per day, and lived an average of thirteen days. Superparasitism occurred in 9.3% of the scales dissected.

Virgin day-old females and males of C. lycimnia were tested at three temperatures (17, 22, 27°C) and two dietary supplements (water, honey and water). Females lived longer than males at all temperature and dietary regimes. Longevity increased as temperature decreased regardless of dietary supplements. Longevity increased when parasitoids were given honey and water as a dietary supplement instead of water alone.

Immature females of C. lycimnia were described and illustrated. There were three instars which were distinguished by mandible length and width, head capsule width, and absence or presence of spiracles. The unusually long duration of 1st instars, and the occurrence of a pupal sheath were discussed. Development from egg to adult was completed in an average of 21 days.

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## CHAPTER I

### INTRODUCTION

Coccophagus lycimnia (Walker) is a cosmopolitan hymenopterous parasitoid in the family Aphelinidae, and is one of 133 described species in the genus Coccophagus (Gordh 1979). Its' cosmopolitan nature is possibly a result of its' vast host range and distribution via commerce of host infested plants (Compere 1931, Gordh 1979). Mated females are primary parasitoids (Flanders 1937, 1943, 1967) of at least 47 species of scale insects in the families Coccidae and Diaspididae; however, only two diaspidids have been reported as hosts and these are questionable (Gordh 1979).

In 1839, Francis Walker first described C. lycimnia, placing it in the genus Aphelinus. Walker stated that the specimens were collected by Mr. Haliday in a greenhouse near Belfast, Ireland, but Graham (1976) was unable to locate the holotype in Mr. Haliday's collection. Graham (1976) found two tag mounted specimens in the British Museum of Natural History labeled Aphelinus lycimnia Walker, one of which was designated lectotype. In 1929, Mercet redescribed Aphelinus lycimnia Walker and placed it in the genus Coccophagus. He stated that several species of Aphelinus described by Walker (1839) were incorrect because the number of antennal segments and the color patterns were attributes of the genus Coccophagus and not Aphelinus. Subsequently, he placed A.

moeris, A. obscurus, A. inaron, A. idaeus, A. scutellaris and A. lycimnia in the genus Coccophagus, and gave specific rank to C. pulchellus Westwood, C. scutellaris (Dalman), and C. lycimnia (Walker). Additionally, he synonymized C. lecanii with C. lycimnia, which was considered, as Mercet (1929) stated, by some North American authors to be synonymous with C. flavoscutellum, C. ater, C. cognatus, C. hawaiiensis, C. coccidis and C. cowperi. In 1931, Compere revised the genus Coccophagus, but did not give specific rank to Coccophagus lycimnia. In the description of Coccophagus scutellaris, he lists C. pulchellus Westwood, A. scutellaris (Walker), A. lycimnia (Walker), A. idaeus (Walker), C. scutellaris (Walker), and A. insidiator var. scutellaris Thompson as the species that Mercet (1929) synonymized with C. scutellaris (Dalman). None of the synonyms listed by Compere as those given by Mercet for C. scutellaris (Dalman) were found in Mercet's paper. Only Entedon scutellaris Dalman, C. lunulatus Howard and C. lunulatus Masi were found as synonyms for C. scutellaris (Dalman) in Mercet's paper. Also, in Compere's (1931) description of C. lecanii, no mention of Mercet's synonym of C. lecanii Smith with C. lycimnia (Walker) was made. Coccophagus lycimnia (Walker) was accepted by some authors as the correct specific name (Flanders 1937, Cendana 1937, Clausen 1956). The species has since been redescribed by de

Santis (1948), Ferrière (1965), and Graham (1976). The redescription made by Ferrière (1965) was based primarily on color; although drawings were presented of the antennae, thorax, and marginal and stigmal veins for the female, while only antennal drawings were presented for the male. Closely related species were separated in a key using developmental differences of males and females. Ferrière (1965) added C. corni Alam and C. taxi Alam to the synonyms list. Graham (1976) did not present a description of C. lycimnia, but only agreed with Ferrière's redescription of C. lycimnia and on the species that Ferrière added as synonyms of C. lycimnia. Graham (1976) stated that he compared specimens of C. lycimnia with the original description of Eulophus scutellaris Nees and considered them to be the same, except for slight differences in color and the number of multiporus plate sensillae of the antennae. Subsequently, he added this species to the synonyms list of C. lycimnia. The most current accepted list of synonyms for C. lycimnia is given by Gordh (1979).

Several taxonomic studies have been made, but the biology of C. lycimnia is not well known. Timberlake (1913) reported that female C. lycimnia oviposited as primary endoparasitoids most of the time, and described the physiological changes of the host as becoming dorso-ventrally blackened as the parasitoid larvae matured. He noticed that females occasionally oviposited as

hyperparasitoids, and that the resulting progeny were male. He was unable to determine those factors affecting sex determination. He further stated that C. lycimnia was normally parthenogenetic and occasionally thelytokous. The factor for sex determination was first reported by Flanders (1936). He found that mated females of C. lycimnia oviposited as primary endoparasitoids, while virgin females oviposited as hyperparasitic ectoparasitoids. He later (1937) reported this species reproduced arrhenotokously. Flanders (1967) elaborated on the developmental sex differences in aphelinids. He reported that unmated females of C. lycimnia and other Coccophagus species oviposit haploid eggs only on primary parasitoid larvae of their own species as well as others that have not voided their meconia, with resulting progeny being all male. Mated females oviposit diploid eggs internally on coccid scales, with resulting progeny being all female. He believed that the autoparasitic nature of C. lycimnia alleviated competitive pressure by removing males from the trophic level of the primary parasitic female. This was considered to benefit the survival of the parasitoid population even when host populations were low. Additionally, he reported that the survival value of this type of development would be enhanced by the early mating of the female parasitoid.

The larval biology of C. lycimnia was reported only for

the male (Flanders 1937). The male egg was attached to the cuticle of a third instar or pupa of a primary parasitoid larva and hatched about three days later. The first instar had 13 segments and contained a single respiratory loop with four pairs of spiracles located on the fourth, sixth, eighth and tenth body segments. Second instars were similar in appearance, except for a more extensive tracheal system and a variable number of spiracles. Third instars differed only in their size and the presence of nine pairs of spiracles. Complete development from egg to adult was 20 days. Although details of female development were not discussed, Flanders (1937) did report females developed from egg to adult in less than 27 days.

Coccophagus lycimnia was reported as a parasitoid of the brown soft scale, Coccus hesperidum, by Timberlake (1913); however, he did not mention the potential this species might have as a biocontrol agent. Later, while conducting research on parasitoids of C. hesperidum occurring on citrus in Texas, Reed et al. (1968) reported C. lycimnia as the most abundant parasitoid attacking C. hesperidum. They decided not to conduct research on C. lycimnia because of its complex life history, and in their opinion it did not control C. hesperidum below economic levels. Ruben and Beirne (1975) reported three species of parasitoids attacking Lecanium tiliae (L.) in British Columbia of which 18% were C. lycimnia. They concluded that

because of the hyperparasitic nature of the unmated female of C. lycimnia, and the scarcity of males found in natural populations, this parasitoid was detrimental to the overall control of L. tiliae.

Since accurate identification of C. lycimnia was difficult because of several morphologically similar species (Compere 1931, Wilk and Kitayama 1981) and from the apparent abundance of C. lycimnia parasitizing C. hesperidum, and L. tiliae (Reed et al. 1968, Rubin and Beirne 1975), it seemed apparent that a redescription as well as a complete biological history of C. lycimnia was necessary not only to assist in species identification, but to initiate studies to determine its effectiveness as a bio-control agent. To this end, my objectives were to provide the following information on C. lycimnia:

1. Provide a redescription of the species;
2. Determine the longevity, fecundity, and optimal host size for oviposition and;
3. Determine the larval morphology and duration of development for the immature female.

## CHAPTER II

### REARING PROCEDURES FOR Coccophagus lycimnia (Walker)

### AND Coccus hesperidum L.

#### i. INTRODUCTION

Brown soft scale hosts for the parasitoid C. lycimnia were mass reared on watermelon, Citrullus vulgaris Schrader. These rearing techniques were used for all tests conducted with C. lycimnia.

#### ii. MATERIALS AND METHODS

Reservoir populations of C. hesperidum and C. lycimnia were reared in an insectary located at the University of Tennessee Plant Science Farm, and in a greenhouse located at the University of Tennessee Agriculture Campus. Rearing procedures for C. hesperidum followed that of Reed et. al. (1968) with the following exception: scale crawlers were not dusted onto the host plant, bird's nest fern, Asplenium nidus L., but allowed to crawl onto them because of inadequate attachment of the crawlers and high mortality. The insectary room was maintained at  $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$  and approximately 50% to 70% RH.

Coccophagus lycimnia were maintained as six independent populations. Five populations were kept in plexiglas chambers, two of which were 40.5cm x 15cm x 15cm, and three

were 15cm cubed. Each chamber had one side covered with fine mesh nylon for easy access to host plants and ventilation of the chamber, and the opposite side had a 12mm hole drilled in it for ease in watering host plants. Two or three bird's nest ferns infested with C. hesperidum were placed into each chamber. A group of both male and female C. lycimnia were released into each chamber. With periodic replacement of hosts the populations were self-sustaining. The sixth population was maintained in the same manner outside the chamber and on ten to fifteen host plants. Lighting was supplied with two 1.22 m fluorescent light fixtures and two 0.04 kw Vitalite® and two 0.04 kw soft white fluorescent bulbs. The light source was positioned approximately 10 cm above the host plants, which supplied approximately 3229.2 lm/m<sup>2</sup>. Environmental conditions were maintained at an RH of 60% ± 10%, a temperature of 27°C ± 2°C, and a photophase of L:D 16:8. The greenhouse populations of C. hesperidum and C. lycimnia were maintained by infesting various plants with C. hesperidum and placing them close to areas where C. lycimnia were found. With periodic replacement of host insects the populations were self-sustaining.

## CHAPTER III

### REDESCRIPTION OF Coccophagus lycimnia (Walker)

#### i. INTRODUCTION

Within the genus Coccophagus, the "lycimnia" group of parasitoids leads to considerable taxonomic confusion (Compere 1931, Wilk and Kitayama 1981). This problem exists primarily because of the lack of diagnostic characters and information on species biology needed to distinguish between closely related species (Compere 1931, Wilk and Kitayama 1981). Compere (1931) stated in his paper on the revision of the genus Coccophagus that color differences within a species varied considerably; that northern specimens were much darker than their more southern counterparts. This extensive use of color differences were used in descriptions and keys to separate species. In Ferrière's (1967) redescription of C. lycimnia, closely related species were separated primarily by differences in sexual development, and descriptions were based mainly on color. Here I have redescribed C. lycimnia and listed characters that may separate it from closely related species.

## ii. MATERIALS AND METHODS

Descriptions were based entirely from specimens collected from populations reared from Coccus hesperidum L. maintained in an insectary at the University of Tennessee plant science farm in Knoxville, Tennessee. Measurements were obtained using a light microscope equipped with an ocular micrometer.

Specimens were first cleared in Essig's aphid fluid (Lambdin and Kosztarab 1973) and then desiccated in 95% ethyl alcohol, and clove oil. Desiccated specimens were then mounted dorsally in a drop of balsam placed on a coverslip. The legs and wings were positioned perpendicular to the body and the balsam allowed to partially dry. Then the coverslip and specimen was placed into fresh balsam on a slide. The coverslip was supported by heat-drawn glass rods to keep the specimens from being crushed. All balsam mounted specimens were dried at 40°C for three weeks before examination.

Temporary slide mounts were made by mounting specimens in Hoyer's mounting medium. Specimens were initially cleared in Essig's aphid fluid and then transferred into a drop of Hoyer's mounting medium on a slide. Heads of specimens were removed from the body and positioned face up to obtain measurements of characters on the front portion of the head.

Specimens for scanning electron microscopy were prepared by freezing living specimens at  $-70^{\circ}\text{C}$  in an ultra low freezer (So Low® freezer). They were then freeze dried at  $-55^{\circ}\text{C}$  for 4h and transferred to SEM studs for silver coating. Characters were photographed with the use of a polaroid camera and a Scanning Electron Microscope, and magnifications were recorded for each.

All measurements were made from balsum and Hoyer's mounted specimens with the use of a phase-contrast microscope equipped with an ocular micrometer. Measurements were taken on 10 individuals unless otherwise noted. Terminology of surface sculpturing follows that of Harris (1979), while antennal character terminology is that of Gibson (1986). All characters were measured and presented in micrometers, except length and width of adults which is presented in millimeters.

### iii. RESULTS AND DISCUSSION

Gordh (1979) compiled synonyms of Coccophagus lycimnia: Aphelinus lycimnia (Walker 1839); Platygaster lecanii (Fitch 1859); Coccophagus lecanii (Smith 1878); C. ater (Howard 1881); C. cognatus (Howard 1881); C. flavoscutellum (Ashmead 1881); C. vividus (Howard 1885); C. californicus (Howard 1889); C. coccidis (Girault 1917); C. corni (Alam 1956); C. taxi (Alam 1956).

**FEMALE DESCRIPTION:** Body of adult female: length 1.1 (0.90-1.3)mm, width 0.32 (0.26-0.42)mm (Plate 1, Fig. 1) Color as follows: head, thorax, abdomen, scape, pedicel, and coxae black. Scutellum with posterior 3/4 yellow; femur black, fading to light yellow distally; tibia yellow with proximal dark brown patch; tarsi, funicular articles, and antennal club light yellow.

**HEAD:** Eyes setose (Plate 2, Fig. 3), setae on head uniformly distributed except for a row along inner ocular margin that extends posterior of facial suture. Head 343 (292-376) wide, 288 (256-308) long, evenly alveolate; facial prominence with 12 (11-14) setae (Plate 2, Fig. 3,4); genal suture present; labial palps 1-segmented; maxillary palps 2-segmented; mandibles tridentate with 2 stout ventral setae and 3 fine frontal setae (Plate 2, Fig. 4); ocelli in equilateral triangle (Plate 2, Fig. 5). Antennae radicle with 9 setae (Plate 2, Fig. 6). Antennal scape 119 (60-164) long, 26 (20-36) wide, with scattered setae, alveolate, triangular (Plate 2, Fig. 3,4); pedicel 47 (44-56) long, 31 (28-36) wide, alveolate, sparsely setose, deltoid-shaped; funicular article I 55 (40-68) long, 35 (28-40) wide, cylindrical, with 4 (3-6) multiporous plate sensillae; article II 48 (40-60) long, 36 (32-40) wide, cylindrical, with 5 (4-7) multiporous plate sensillae; article III 46 (40-56) long, 41 (32-48) wide, cylindrical, with 6 (5-7) multiporous plate sensillae; antennal club consisting of

PLATE 1. General appearance of adult ♀ and ♂ Coccophagus  
lycimnia.

Figure 1. Adult ♀ C. lycimnia (45x).

Figure 2. Adult ♂ C. lycimnia (45x).



PLATE 2. Head and antennal characters of adult ♀  
Coccophagus lycimnia.

Figure 3. Frontal view of head (189x).

Figure 4. Mandibles (220x).

Figure 5. Ocellar triangle (360x).

Figure 6. Radicle of antenna (1080x).

Figure 7. Sensilla of antennal club tip (3000x).

Figure 8. Multiporus plate sensilla of antenna (250x).

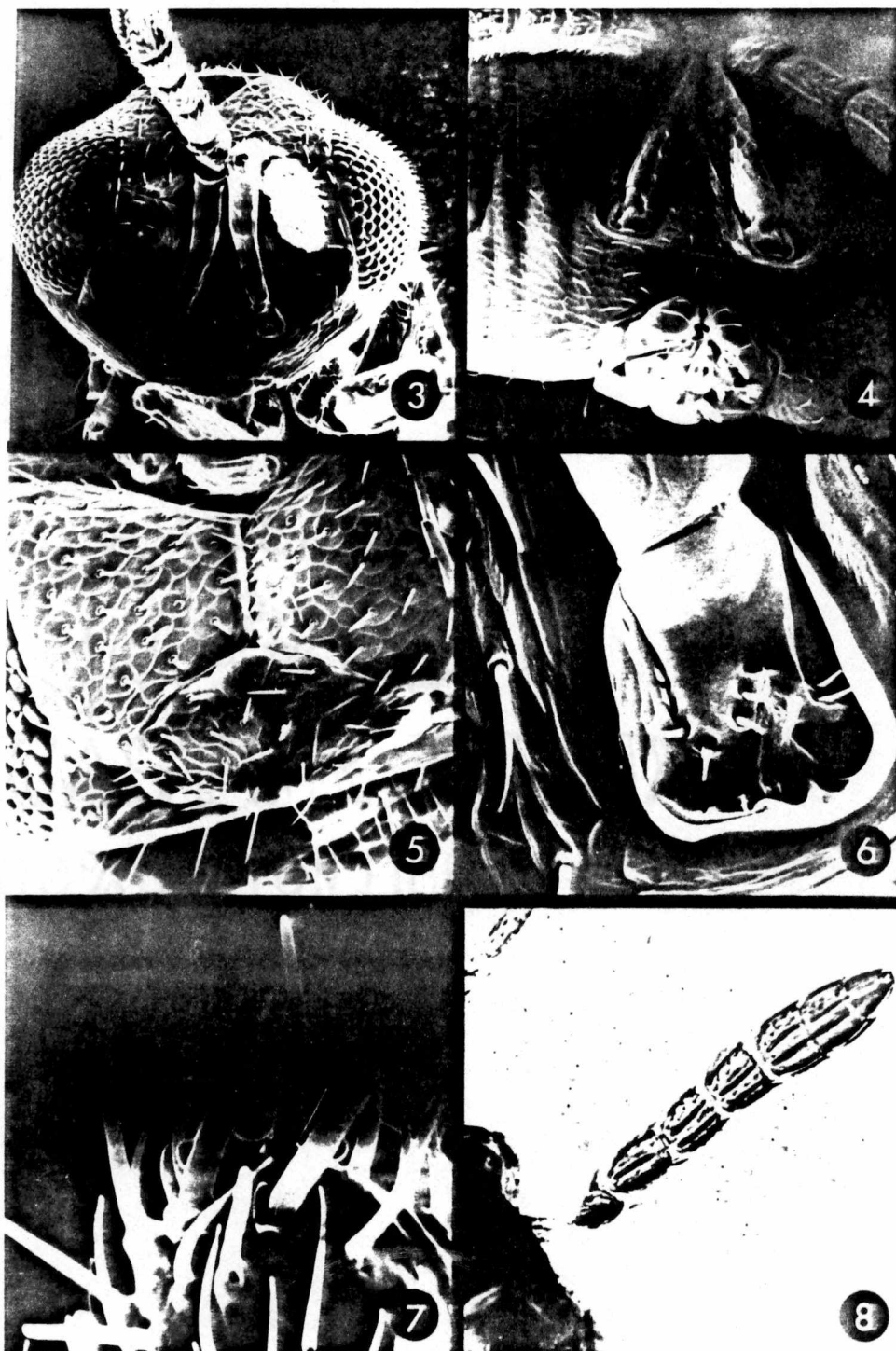


PLATE 2

three segments, the basal two cylindrical, club segment I 41 (32-52) long, club segment II 36 (32-40) long, and the terminal segment 34 (20-40) long, triangular from lateral view, and terminating with 5 (4-5) blunt trichoid sensillae (Plate 2, Fig. 7); antennal club with 19 (16-23) multiporous plate sensillae; club and funicular articles with longitudinal rows of setae. All setae of antennae needlelike, 12 (4-20) long (Plate 2, Fig. 8).

THORAX: Pronotum imbricate, setae uniformly distributed over entire surface except along margin. Marginal setae distributed evenly, and 21 (16-28) long, each posterolateral margin with one seta longer than the other pronotal setae, length of posterolateral setae 47 (36-60) (Plate 3, Fig. 9). Mesoscutum with 77 (56-94) setae uniformly distributed, and 23 (16-32) long. Margin of mesoscutum with 13 (11-16) evenly distributed setae longer than the others, and 41 (28-60) long (Plate 3, Fig. 10). Each parapsis with 4 (2-5) setae, 24 (12-32) long, and a group of 3 fine setae less than 1 micron long (Plate 3, Fig. 9); each axilla with 2 (2-4) setae, proximal setae longer than the others, length 57 (36-76):37 (16-48), and each tegula with 2 (2) setae, length 30 (20-40) (Plate 3, Fig. 9,10). Scutellum with 3 pairs of setae in two sublateral, longitudinal rows, each pair progressively becoming longer posteriorly, first pair 55 (40-68) long, second pair 68 (56-80) long, and third pair 96 (80-120) long (Plate 3, Fig. 10), supernumary setae

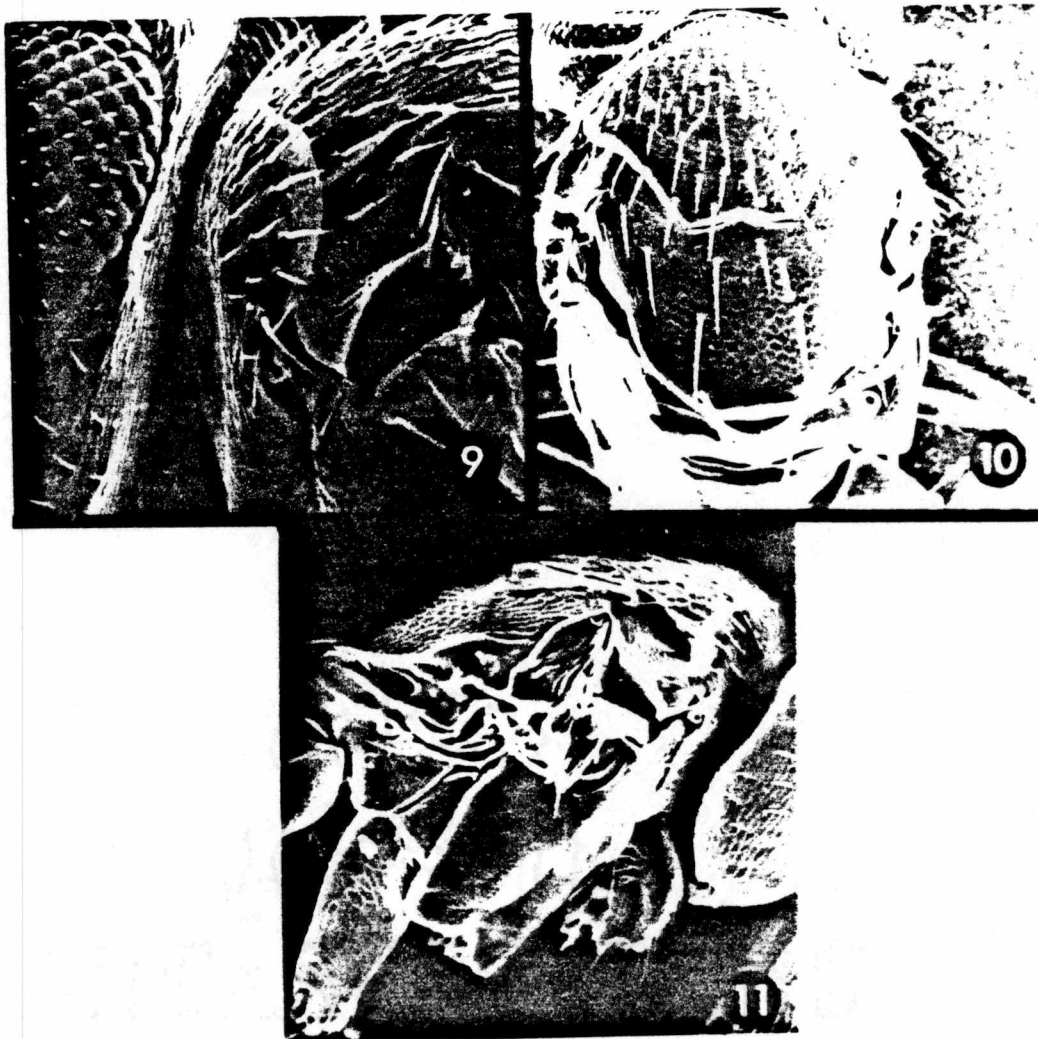


PLATE 3. Thoracic characters of adult ♀ Coccophagus lycimnia.

Figure 9. Lateral view of pronotum, axilla, and tegula (220x).

Figure 10. Dorsal view of thorax (120x).

Figure 11. Lateral view of Thorax (120x).

sometimes present (Plate 3, Fig. 10). Mesoscutum, axillae, parapsis, prepectus, and metapleuron imbricate (Plate 3, Fig. 10,11). Metanotum imbricate laterally, becoming faint medially (Plate 3, Fig 10). Scutellum alveolate, fading anteriorly and laterally (Plate 3, Fig. 10). Mesopleuron faintly strigulate (Plate 3, Fig. 11). LEGS: All leg measurements are presented in tables 1 and 2.

Table 1. Length of leg segments of ♀ Coccophagus lycimnia.

| Leg Segments | Lengths Prothoracic | Lengths Mesothoracic | Lengths Metathoracic |
|--------------|---------------------|----------------------|----------------------|
| Coxa         | 118 (72-156)        | 102 (84-144)         | 152 (120-220)        |
| Trochanter   | 61 (52-80)          | 77 (64-92)           | 75 (56-96)           |
| Femur        | 157 (136-208)       | 220 (172-272)        | 160 (100-240)        |
| Tibia        | 136 (96-184)        | 258 (180-320)        | 254 (196-308)        |
| Tarsus       | 190 (120-224)       | 226 (180-284)        | 249 (208-300)        |
| Total Length | 652 (476-852)       | 883 (680-1112)       | 890 (680-1164)       |

Table 2. Width of leg segments of ♀ Coccophagus lycimnia.

| Leg Segments | Width Prothoracic | Width Mesothoracic | Width Metathoracic |
|--------------|-------------------|--------------------|--------------------|
| Coxa         | 67 (52-92)        | 62 (52-88)         | 83 (68-100)        |
| Trochanter   | 31 (24-32)        | 41 (32-44)         | 48 (32-48)         |
| Femur        | 41 (36-44)        | 48 (44-56)         | 63 (56-72)         |
| Tibia        | 32 (28-40)        | 32 (24-40)         | 30 (28-38)         |

Prothoracic legs; coxae imbricate, setose dorsally; tibial spur curved and bifid. Strigil with 8 teeth (Plate 4, Fig. 13). Mesothoracic legs; coxa setose ventrally.

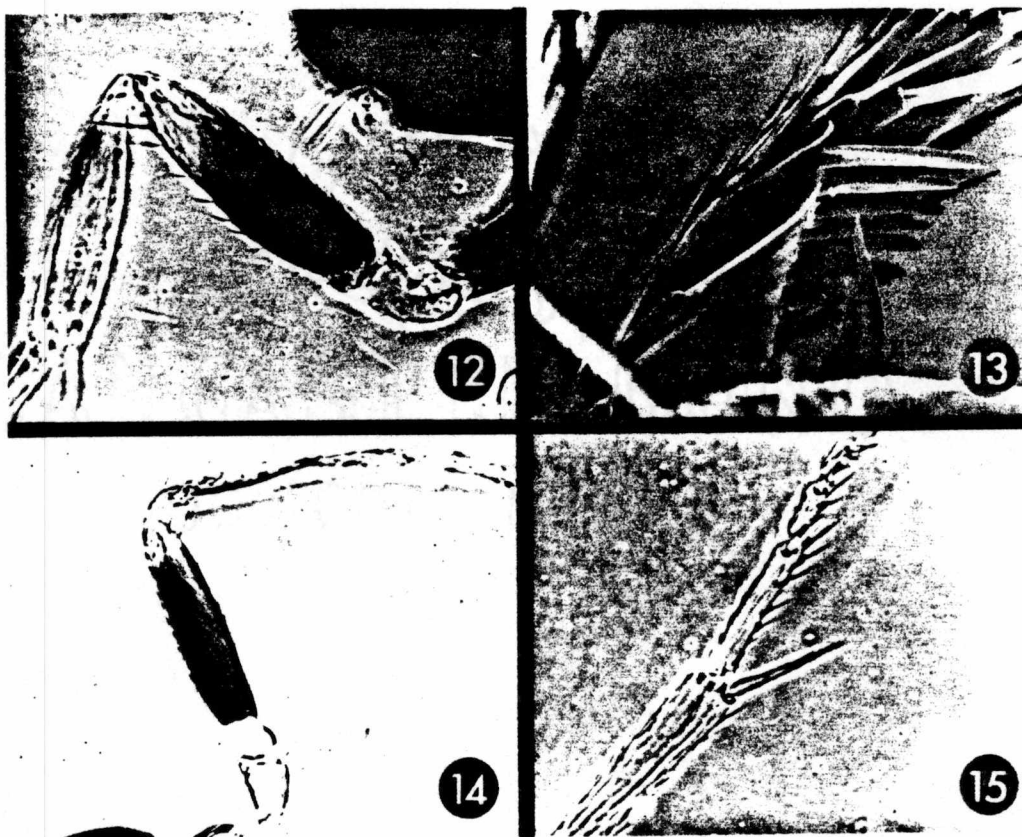


PLATE 4. Leg characters of adult ♀ Coccophagus lycimnia.

Figure 12. Row of ventral setae of prothorasic femur (200x).

Figure 13. Strigil of prothorasic basitarsus (1400x).

Figure 14. Row of ventral setae of mesothorasic femur (200x).

Figure 15. Mesothorasic tibial spur and basitarsus (600x).

Metathoracic legs; coxa with scattered setae restricted to distal fourth of coxa. All coxae quadrate; trochanters with scattered setae; femora with scattered dorsal setae, and a row of ventral setae longer than others, longest distal setae of pro, meso, and metathoracic femur 33 (28-44), 27 (20-36), 15 (8-24) (Plate 4, Fig. 12,14); tibia randomly setose. Ratio of pro, meso, and metathoracic tibial spur to basitarsus length 46 (36-56): 69 (48-80), 78 (68-92): 106 (80-128), 38 (28-44): 91 (80-120) (Plate 4, Fig. 15). Leg setae needle-like in appearance. All leg setae lengths are presented in table 3. Basitarsae longer than other tarsomeres.

Table 3. Setae length on leg segments of ♀ Coccophagus lycimnia.

| Leg Segments | Setae Length Prothoracic | Setae Length Mesothoracic | Setae Length Metathoracic |
|--------------|--------------------------|---------------------------|---------------------------|
| Coxa         | 10 (8-20)                | 10 (8-16)                 | 20 (8-36)                 |
| Trochanter   | 10 (8-12)                | 12 (8-16)                 | 13 (4-20)                 |
| Femur        | 14 (12-16)               | 14 (8-16)                 | 12 (8-20)                 |
| Tibia        | 11 (4-24)                | 14 (8-20)                 | 17 (8-20)                 |
| Tarsus       | 12 (8-16)                | 17 (8-24)                 | 14 (8-20)                 |

#### ABDOMEN:

Propodeum 307 (240-380) wide, imbricate laterally becoming faint medially, spiracles submarginal, two setae posterolaterally of spiracles (Plate 3, Fig. 10). Petiole 29 (24-36) long, 168 (136-208) wide. Abdominal tergites I through IV smooth medially and becoming faintly imbricate

laterally. Abdominal tergite I 94 (60-120) long, 330 (268-408) wide. Transverse row of setae beginning on submedial region of tergites II, III, IV and continuing around lateral margin (Plate 5, Fig. 16); tergites II, III, IV length 91 (72-124), width 359 (292-440); 80 (72-104), 353 (292-420), 74 (60-88), 344 (300-444) respectively. Tergites V, VI with a posterior, transverse row of setae (Plate 5, Fig. 16); imbrication faint and even; tergite V, IV 78 (64-92) long, 314 (256-384) wide, 71 (52-84) long, 254 (200-300) wide respectively. Tergite VII 75 (52-120) long, 180 (148-212) wide, triangular viewed dorsally, with 10 (9-13) setae, setae 28 (20-40) long; imbrication faint and coming to sharp posterior points (Plate 5, Fig. 17); cerci situated closer to posterior spiracles than end of abdomen; with 3 long setae and one short seta (Plate 5, Fig. 18). Abdominal sternites with 14 (8-40) setae randomly distributed, becoming sparse anteriorly and laterally, setae 19 (8-36) long. Gonotergite of ovipositor plate with several basal setae; gonocoxite with two setae on each side (Plate 5, Fig. 19); ovipositor sheath with 17 (14-19) long, curved setae (Plate 5, Fig. 20); ovipositor 275 (236-308) long, 16 (16) wide (Plate 5, Fig. 19).

WINGS: Forewing 764 (647-941) long, 301 (245-402) wide, disk setose, disk setae 9 (8-12) long, margin with setae around curvature of wing causing a fringed appearance (Plate 6, Fig. 21), margin setae 21 (12-36) long; costal cell with

PLATE 5. Abdominal characters of adult ♀ Coccophagus  
lycimnia.

Figure 16. Setal pattern and ovipositor plate of abdomen (150x).

Figure 17. Sculpturing of abdominal tergites 6, 7, and 8 (300x).

Figure 18. Cercus plate (1280x).

Figure 19. Setae of ovipositor plate (300x).

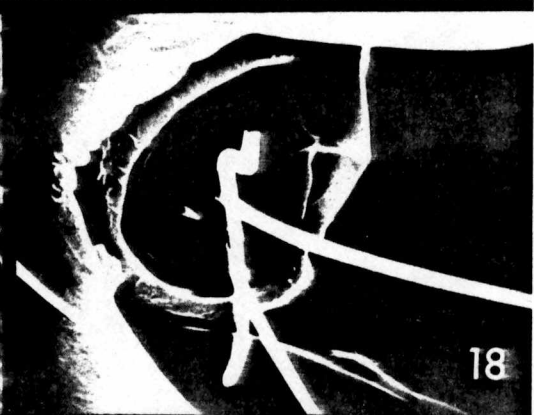
Figure 20. Sensilla of ovipositor sheath tip (630x).



16



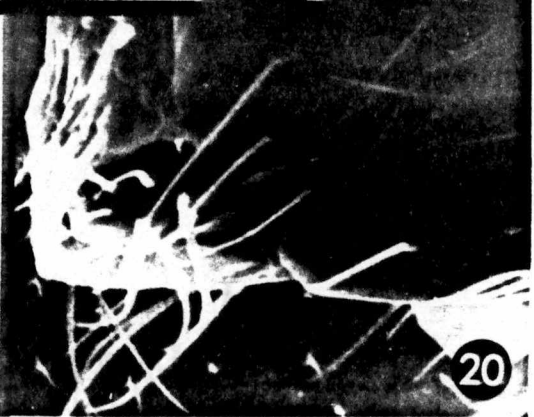
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20

PLATE 5

PLATE 6. Wing characters of adult ♀ Coccophagus lycimnia.

Figure 21. Setal pattern of forewing (150x).

Figure 22. Setae of costal vein and bullae of submarginal vein of forewing (400x).

Figure 23. Submarginal, marginal, and stigmal vein of forewing (200x).

Figure 24. Setal pattern of hindwing (200x).

Figure 25. Submarginal and marginal vein of hindwing (300x).

Figure 26. Hamuli of hindwing (2700x).

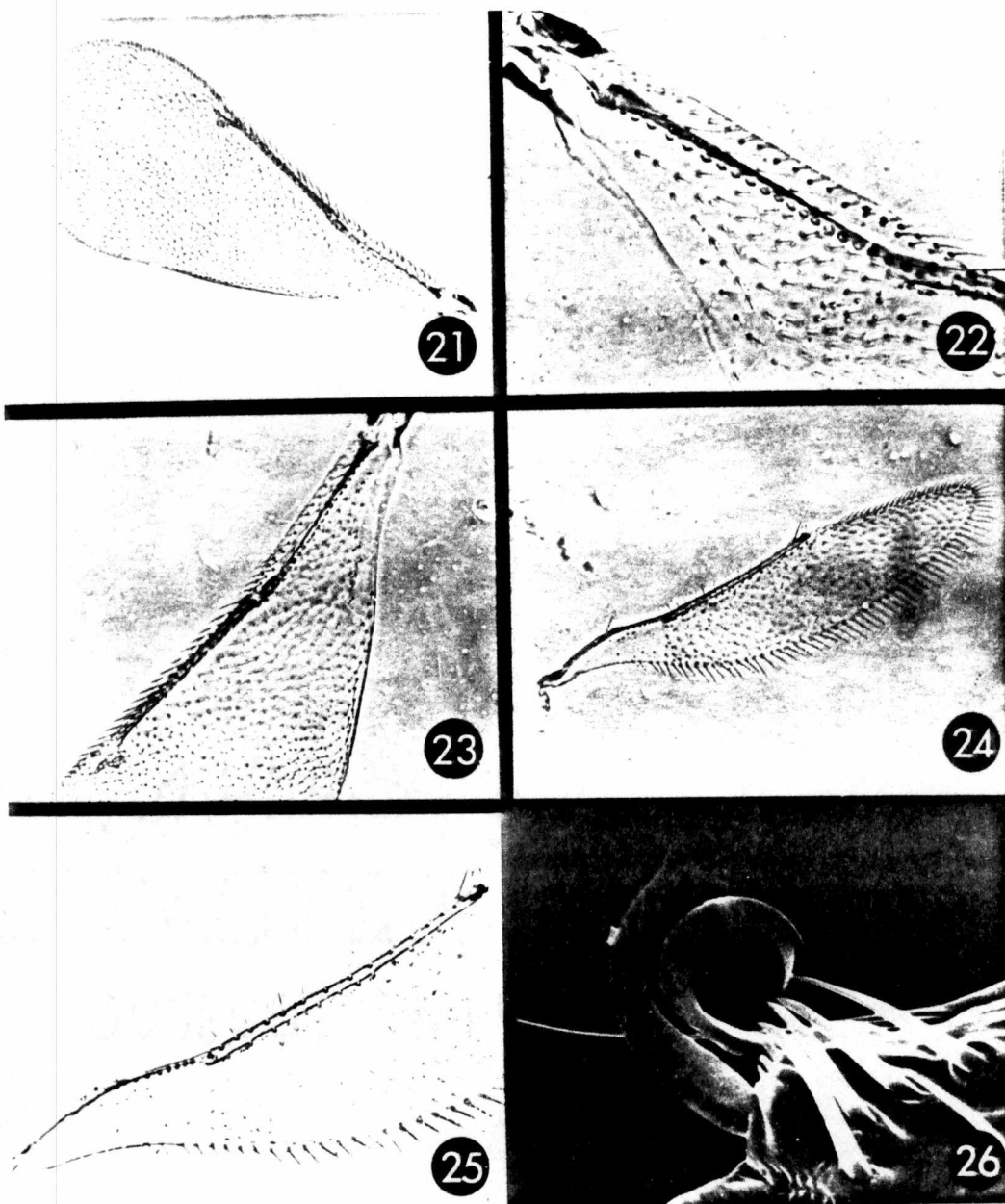


PLATE 6

21 (16-23) setae; submarginal vein with 19 (16-24) bullae (Plate 6, Fig. 2), and 10 (9-12) setae, 32 (24-52) long. Two discoid sensillae located apical of bullae; marginal vein with numerous setae, 27 (24-32) long; length submarginal vein: marginal vein 218 (186-265): 249 (196-333) (Plate 6, Fig. 23); stigmal vein with four discoid sensillae arranged in two pair (Plate 6, Fig. 23). Hindwing 617 (519-882) long, 115 (98-167) wide, with apical  $\frac{3}{4}$  of disk sparsely setose (Plate 6, Fig. 24), disk setae 9 (8-12) long, margin with setae around curvature of wing causing a fringed appearance (Plate 6, Fig. 24), marginal setae longer and more widely spaced than those of the forewing, marginal setae 35 (12-52) long; submarginal vein with 2 short setae and 1 long seta, the long seta between the two short setae, and the group located mid-vein, long seta 23 (20-28) long, short setae 6 (4-8) long (Plate 6, Fig. 25); marginal vein with 15 (9-20) setae (Plate 6, Fig. 25), 18 (16-24) long; hamuli with 2 (2) fringed wing hooks and a row of 4 (4) posterior setae (Plate 6, Fig. 26); length submarginal vein: marginal vein 198 (168-224): 228 (180-256).

**MALE DESCRIPTION:** Body 0.90 (0.69-1.1)mm long, 0.25 (0.13-0.31)mm wide. Differs from female by possessing: a black scutellum, sometimes with rim of yellow around base (Plate 1, Fig. 2, p. 13). Antennae distinctly more robust, and with more multiporous plate sensillae (Plate 7, Fig. 27). Scape 104 (88-116) long, 30 (28-36) wide; pedicle 46



PLATE 7. Antennal and abdominal characters of adult ♂  
Coccophagus lycimnia.

Figure 27. Multiporus plate sensilla of antenna (200x).

Figure 28. Aedeagus (300x).

(44-48) long, 32 (28-36) wide; funicle I 65 (52-72) long, 43 (40-48) wide, with 11 (8-15) multiporous plate sensillae; funicle II 55 (48-60) long, 43 (40-48) wide, with 10 (9-13) multiporous plate sensillae; funicle III 52 (48-56) long, 45 (40-52) wide, with 9 (8-12) multiporous plate sensillae; club 136 (124-148) long, 46 (36-52) wide, with 26 (22-43) multiporous plate sensillae. Forewing 673 (588-735) long, 298 (275-324) wide; submarginal vein length: marginal vein length 189 (176-216): 223 (205-235); hindwing 548 (490-598) long, 108 (88-127) wide; submarginal vein length: marginal vein length 173 (144-176): 198 (165-204). Aedeagus 121 (115-124) long (Plate 7, Fig. 28).

All character data were analyzed using correlation coefficient and coefficient of variation procedures (SAS Institute 85). Those characters with correlation coefficients of 70% or greater and coefficients of variation less than 10% were considered relatively stable and deemed potentially useful for species separation. Results are presented for both males and females in tables 4-13.

Table 4. Correlation coefficients for head and antennae characters of ♀ Coccophagus lycimnia.

| character       | CC   | mean length(μm) |
|-----------------|------|-----------------|
| scape:funicle 1 | 0.89 | 119:55          |
| scape:funicle 2 | 0.85 | 119:48          |
| scape:funicle 3 | 0.94 | 119:46          |

Table 5. Correlation coefficients for thorax characters of ♀ Coccophagus lycimnia.

| character                           | CC   | mean length(μm) |
|-------------------------------------|------|-----------------|
| scutellum setae 1:scutellum setae 2 | 0.91 | 55:68           |
| scutellum setae 2:scutellum setae 3 | 0.86 | 68:96           |

Table 6. Correlation coefficients for wing characters of ♀ Coccophagus lycimnia.

| character                                    | CC   | mean length(μm) |
|----------------------------------------------|------|-----------------|
| marginal vein:submarginal vein<br>(forewing) | 0.85 | 249:218         |
| marginal vein:submarginal vein<br>(hindwing) | 0.96 | 228:198         |

Table 7. Correlation coefficients for leg characters of ♀ Coccophagus lycimnia.

| character                     | CC   | mean length(μm) |
|-------------------------------|------|-----------------|
| <b>Prothoracic legs</b>       |      |                 |
| coxa:tarsus                   | 0.76 | 123:190         |
| femur:tibia                   | 0.84 | 157:136         |
| tarsus:basitarsus             | 0.92 | 190:69          |
| <b>Mesothoracic legs</b>      |      |                 |
| coxa:trochanter               | 0.83 | 102:77          |
| coxa:femur                    | 0.85 | 102:220         |
| coxa:tibia                    | 0.85 | 102:258         |
| trochanter:femur              | 0.83 | 77:220          |
| femur:tibia                   | 0.95 | 220:258         |
| tarsus:tibia                  | 0.93 | 226:258         |
| tibia:basitarsus              | 0.80 | 258:89          |
| tarsus:basitarsus             | 0.81 | 226:89          |
| <b>Metathoracic legs</b>      |      |                 |
| coxa:femur                    | 0.80 | 152:160         |
| femur:tibia                   | 0.76 | 160:254         |
| tarsus:femur                  | 0.74 | 249:160         |
| tarsus:tibia                  | 0.95 | 249:254         |
| basitarsus:tibia              | 0.93 | 91:254          |
| basitarsus:tarsus             | 0.95 | 91:249          |
| basitarsus:tarsal segment two | 0.79 | 91:46           |

Table 8. Coefficients of variation for characters of ♀ Coccophagus lycimnia.

| character                             | CV   | mean length(μm)/number |
|---------------------------------------|------|------------------------|
| antennae club                         | 6.67 | 114μm                  |
| pedicel length                        | 9.05 | 47μm                   |
| facial prominence                     | 9.09 | 12 setae               |
| head width                            | 6.37 | 343μm                  |
| submarginal vein length<br>(forewing) | 8.98 | 218μm                  |
| ovipositor length                     | 8.68 | 275μm                  |
| ovipositor width                      | 0.00 | 16μm                   |

Table 9. Correlation coefficients for head and antennae characters of ♂ Coccophagus lycimnia.

| character              | CC   | mean length(μm) |
|------------------------|------|-----------------|
| club:pedicel           | 0.76 | 136:46          |
| club:funicle segment 3 | 0.76 | 136:52          |
| club:club segment 1    | 0.84 | 136:50          |
| club:club segment 2    | 0.74 | 136:45          |

Table 10. Correlation coefficients for thorax and wing characters of ♂ Coccophagus lycimnia.

| character                                    | CC   | mean length(μm) |
|----------------------------------------------|------|-----------------|
| scutellum setae pair 1<br>:                  | 0.71 | 54:67           |
| scutellum setae pair 2                       |      |                 |
| mesoscutellum margin setae<br>:              | 0.70 | 39:23           |
| mesoscutellum interior setae                 |      |                 |
| marginal vein:submarginal vein<br>(forewing) | 0.83 | 223:189         |
| marginal vein:submarginal vein<br>(hindwing) | 0.85 | 195:173         |

Table 11. Correlation coefficients for leg characters of ♂ Coccophagus lycimnia.

| character               | CC   | mean length(μm) |
|-------------------------|------|-----------------|
| Prothoracic legs        |      |                 |
| coxa:femur              | 0.74 | 111:149         |
| femur:tibia             | 0.81 | 149:133         |
| tarsus:tibia            | 0.71 | 187:133         |
| basitarsus:tibia        | 0.85 | 66:133          |
| basitarsus:tarsus       | 0.76 | 66:187          |
| tibial spur:tibia       | 0.99 | 45:133          |
| tibial spur:basitarsus  | 0.70 | 45:66           |
| Mesothoracic legs       |      |                 |
| coxa:femur              | 0.80 | 93:201          |
| coxa:tibia              | 0.78 | 93:237          |
| tarsus:tibial spur      | 0.77 | 221:54          |
| Metathoracic legs       |      |                 |
| coxa:femur              | 0.90 | 138:167         |
| femur:tibia             | 0.75 | 167:220         |
| tarsus:basitarsus       | 0.92 | 230:89          |
| tarsus:tarsal segment 5 | 0.70 | 230:63          |

Table 12. Coefficients of variation for antenna, thorax, wing, and abdomen characters of ♂ Coccophagus lycimnia.

| character                 | CV   | mean length(μm) |
|---------------------------|------|-----------------|
| scape                     | 5.66 | 104             |
| pedicel                   | 4.56 | 46              |
| funicle segment 1         | 8.27 | 65              |
| funicle segment 2         | 5.63 | 55              |
| funicle segment 3         | 5.44 | 52              |
| club                      | 5.50 | 136             |
| club segment 1            | 7.77 | 50              |
| club segment 2            | 6.13 | 45              |
| club segment 3            | 9.58 | 44              |
| scutellum setae pair 1    | 5.60 | 54              |
| scutellum setae pair 2    | 5.67 | 67              |
| scutellum setae pair 3    | 7.83 | 84              |
| axillary seta             | 5.13 | 57              |
| marginal vein hindwing    | 6.41 | 195             |
| submarginal vein hindwing | 7.85 | 173             |
| aedeagus length           | 6.59 | 121             |

Table 13. Coefficients of variation for leg characters of ♂ Coccophagus lycimnia.

| character         | CV   | mean length(μm) |
|-------------------|------|-----------------|
| Prothoracic legs  |      |                 |
| coxa              | 7.23 | 111             |
| tarsus            | 4.99 | 187             |
| basitarsus        | 7.83 | 66              |
| tarsus segment 4  | 6.81 | 45              |
| Mesothoracic legs |      |                 |
| femur             | 2.81 | 201             |
| trochanter        | 7.84 | 67              |
| tibia             | 4.70 | 237             |
| tarsus            | 5.65 | 221             |
| tibial spur       | 9.02 | 69              |
| basitarsus        | 8.19 | 89              |
| Metathoracic legs |      |                 |
| tarsus            | 5.81 | 230             |
| tibial spur       | 8.75 | 41              |

## CHAPTER IV

### OPTIMAL LENGTH OF Coccus hesperidum L.

#### FOR PARASITISM BY Coccophagus lycimnia (Walker)

##### i. INTRODUCTION

Knowledge of optimal host length for parasitism is essential for successful use of parasitoids in biocontrol programs as well as in other biological studies. Several methods have been used to determine the optimum development of scale hosts for parasitism by C. lycimnia (Walker) (Cendana 1937, Flanders 1952, Flanders et al. 1961, Reed et al. 1968). Reed et al. (1968) reported the optimal age of the brown soft scale, C. hesperidum L., for parasitism to be 25 to 31 days old. Cendana (1937) reported the optimal stage of development of Saissetia hemispherica (Targ.) for parasitism by Coccophagus ochraceus Howard to be late first to early second instars. Flanders (1952) listed the preferred stages of development of the black scale, Saissetia oleae (Bern.), for parasitism by several Coccophagus species. Later, Flanders et al. (1961) reported the optimum length of C. hesperidum for parasitism by Coccophagus basalis (Comp.) to be from 0.8 to 1.1mm. Because of host-plant interactions, species develop differently depending on their host plant (Miller and

Kosztarab 1979). The use of age and stage of development for parasitoid oviposition tests are limited to specific host plants. However, optimal length for parasitism remains constant regardless of what host plant is used. My objective was to determine the optimum length of C. hesperidum for parasitism by mated female C. lycimnia.

## ii. MATERIALS AND METHODS

Potted bird's nest ferns, Asplenium nidus L., maintained in an environmental room at  $27 \pm 2^\circ\text{C}$ ,  $60 \pm 10\%$  RH, and a photoperiod of L:D 16:8, were infested with a cohort of 24 h-old brown soft scale crawlers. When all stages of scales were present (ca. 27 days) a frond was removed from a bird's nest fern and sectioned into ca. 2.5 cm squares. Each frond square was braced by a clay base at a  $45^\circ$  angle and placed in a plastic petri dish (100 x 15 mm) with the bottom lined with 9 cm filter paper to allowed potential hosts on both sides of the frond square to be exposed to parasitism. This procedure was replicated five times. A mixture of ca. 50 C. lycimnia adult males and females of varying ages was placed in each petri dish and returned to a different environmental room. After 24h, both parasitoids and hosts were removed. Each scale insect was measured with the use of a light microscope and an ocular micrometer, and then dissected in Ringer's saline under a dissecting microscope. Data were recorded on scale length and the

number of parasitoid eggs per scale.

Successful emergence rate was determined by placing a bird's nest fern infested with 24-h old C. hesperidum into a 20 x 20 cm plexiglass chamber covered on one side by nylon, and placing it in an environmental room maintained. Once all stages of the scale were found a group of adult male and female C. lycimnia of varying ages was put into the plexiglass chamber. After several generations of C. lycimnia occurred, two fronds were removed from the bird's nest fern, and all scales with emergence holes were removed, measured, and data recorded on the scale length.

All measurements were grouped into 100 $\mu$ m ranges for ease of data comparison. Percent parasitism was calculated by dividing the number of parasitized scales in each 100 $\mu$ m length range by the total number of scales offered (n=380), then multiplied by 100. Percent emergence was calculated by dividing the number of scales with emergence holes in each 100 $\mu$ m length range by the total number of scales with emergence holes (n=112), then multiplied by 100.

### iii. RESULTS AND DISCUSSION

The length of C. hesperidum ranged from 500 to 3200 $\mu$ m (n=380). Although the number of scales from 500 to 1000 $\mu$ m long and from 1600 to 3100 $\mu$ m long constituted 48% of the population available for parasitism, only 14% were

parasitized (Fig. 1). Parasitism increased to 22% in scales that ranged from 1100 to 1500 $\mu$ m long. Emergence occurred in 71% of the scales from 1400 to 1700 $\mu$ m long (Fig.2). These results were indicative of a higher parasitism rate in scales that range from 1100 to 1500 $\mu$ m in length, and that scales continue to develop a period of time after being parasitized.

Emergence occurred in less than 6% of the scales that were greater than 2000 $\mu$ m in length. This may occur because C. lycimnia may have difficulty reaching the oviposition site in the mesenteron of its host. These results are similar to those reported by Flanders et al. (1961) who found that very few brown soft scales parasitized by C. basalis were greater than 2000 $\mu$ m in length. He concluded that this may happen because the ovipositor of the parasitoid is too short to reach the oviposition site in the subesophageal ganglion of scales greater than 2000 $\mu$ m long.

C. lycimnia oviposited primarily in brown soft scales that are 1100 to 1500 $\mu$ m long, and once oviposition was complete, the scales continue to develop. Additionally, successful development of C. lycimnia in scales greater than 2000 $\mu$ m long may not often occur because of the unusual oviposition site of C. lycimnia.

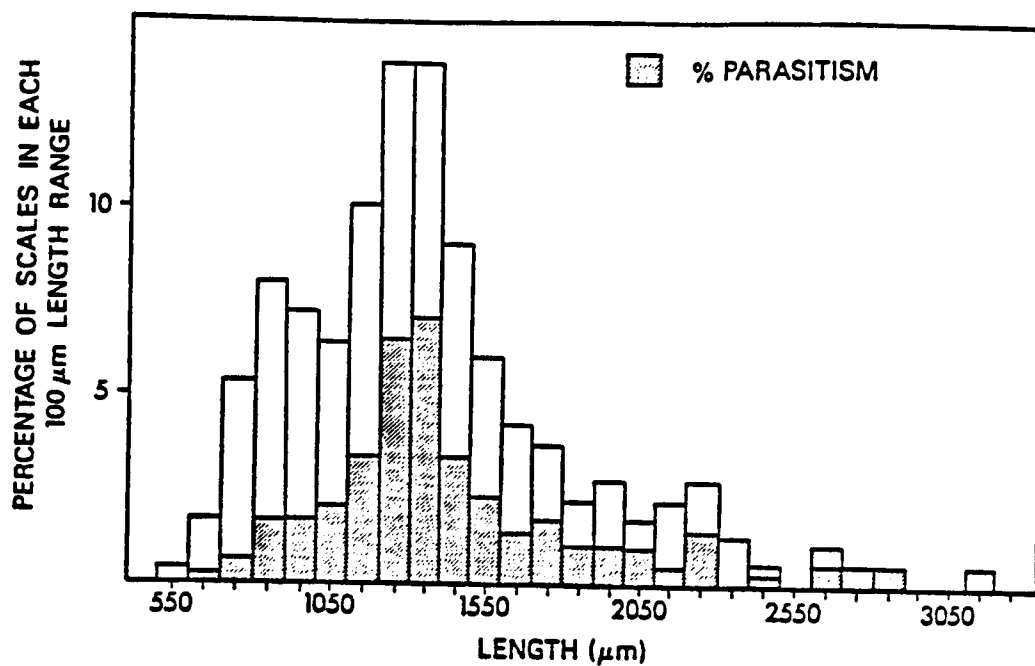


Figure 1. Parasitism of different sizes of Coccus hesperidum by Coccophagus lycimnia.

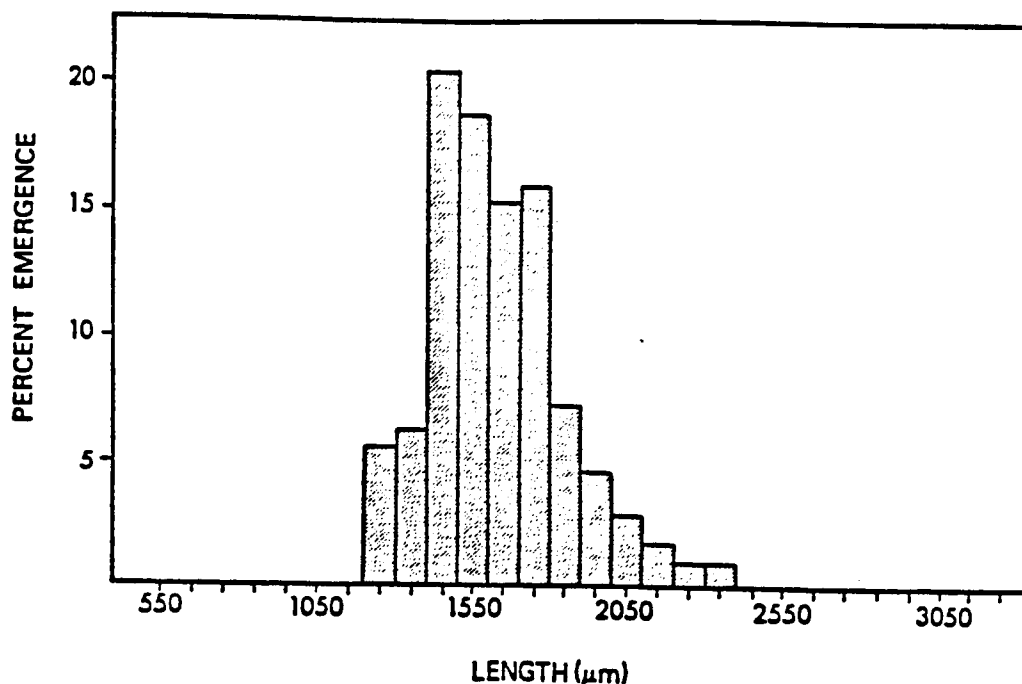


Figure 2. Emergence of Coccophagus lycimnia from different sizes of Coccus hesperidum.

## CHAPTER V

### LONGEVITY AND FECUNDITY OF Coccophagus lycimnia (Walker)

#### i. INTRODUCTION

Basic biological research of predators and parasitoids is essential for successful implementation in an integrated approach to pest control (Knipling 1979). Coccophagus lycimnia (Walker) may prove to be a successful biocontrol agent of the brown soft scale, Coccus hesperidum L.; however, little of its' biology is known. In this paper I present the results of fecundity and longevity tests conducted for C. lycimnia.

#### ii. MATERIALS AND METHODS

##### LONGEVITY:

Longevity tests were conducted on 24 h-old virgin male and virgin female C. lycimnia at three temperatures (17,22,27°) and two dietary supplements (honey and water, water). Each temperature and dietary regime was replicated ten times where each parasitoid was considered a biological replicate. All tests were conducted in an environmental room maintained at 60±10% RH and a photoperiod of L:D 16:8. Each parasitoid was placed in a 40 x 15mm plastic petri dish lined with 4 cm filter paper and supplied with the appropriate dietary supplement, then dated and placed in an

environmental room maintained at the appropriate temperature. Honey was supplied by smearing a drop on the petri dish lid, and distilled water was supplied in a 35 x 10mm glass vial and plugged with cotton covered by fine mesh nylon. Water vials were adhered to the petri dish with clay. Parasitoids were examined daily for mortality. When parasitoids were found dead, the date of death was recorded.

FECUNDITY:

Potted six inch bird's nest ferns, Asplenium nidus L., were maintained in an environmental room at  $27 \pm 2^{\circ}\text{C}$ ,  $60 \pm 10\%$  RH, and a photoperiod of L:D 16:8. Ferns were watered to saturation every other day and fertilized ca. every 3 months with Rapid Grow® 15-30-15 fertilizer at a rate of five ml/l of water. Brown soft scale crawlers were allowed to crawl onto the ferns from their watermelon hosts for 24-h. The ferns were then returned to the environmental room. Once the majority of scales developed to the appropriate length (1100 to 1500 $\mu\text{m}$ ), a section of frond containing a mean of 70 scales was removed and placed in a 60 x 15mm petri dish. Potential hosts were exposed to parasitoids by positioning the frond at a  $45^{\circ}$  angle using a clay base. Each petri dish was supplied with a vial of water and 100% honey. Distilled water was supplied in a 35 x 10mm glass vial plugged with cotton covered by fine mesh nylon. The honey was supplied by smearing a drop across the petri dish lid. This method prevented death of the parasitoids by entanglement. A

mixture of four 24-h old virgin males and four 24-h old virgin females was placed in each of six prepared petri dishes. The experimental design used was a randomized complete block with two blocks and three replications. After 24-h the parasitoids and scales were removed. The scales were placed in a drop of Ringer's saline on a glass slide and dissected using a dissecting microscope. Data recorded were the number of scales, parasitized scales, and parasitoid eggs in each parasitized scale.

### iii. RESULTS AND DISCUSSION

#### LONGEVITY:

Females lived longer than males at all temperatures and dietary treatments. This difference was especially pronounced at 17°C with a dietary supplement of water and honey where females lived a mean of 52.2 (36-64) days and males lived a mean of 22.9 (15-32) days. These results support earlier findings by Cendana (1931) who reported females of five Coccophagus spp. lived longer than their male counterparts.

Temperature was not as detrimental to the survivability of C. lycimnia as the dietary supplements. Males and females at all tested temperatures lived less than six days when given a dietary supplement of water only; however, when given water and honey as a dietary supplement, males and

females lived at least 12 (5-41) days and as great as 52 (8-64) days (Table 14).

Although the longevity of male and female C. lycimnia increased as temperature decreased, the longevity of the females increased greater than two times the longevity of their male counterparts when given honey and water.

#### FECUNDITY:

Mated female C. lycimnia adults deposited a mean of 5.6 (0-20) eggs/day and lived a mean of 12.6 (1-31) days. The longevity of egg-laying parasitoids was considerably less than non egg-laying parasitoids. The number of eggs deposited each day varied considerably. One parasitoid deposited 22 eggs in a 24 h period then only 3 the following 24 h period. Erratic egg deposition occurred over the entire life of the parasitoid. This behavior was also reported for C. gurneyi (Cendana 1937). He found C. gurneyi oviposited up to 67 eggs in 2 days then not oviposit again for 3 days. Even though it was difficult to determine a peak oviposition period, a greater number of eggs appeared to be laid during the first two weeks of the parasitoids life. (Fig. 3).

Although uncommon, superparasitism did occur. Of the 6854 scales offered as hosts for parasitism, 21% were parasitized, of these 90.7% contained a single egg, 8.6% contained two eggs, and 0.7% contained more than 2 eggs. Similar results were reported for C. cardi

Table 14. Effects of temperature and dietary supplements on longevity of adult Coccophagus lycimnia.

| Temp. (°C)      | Longevity $\pm$ SE |                |     |                |
|-----------------|--------------------|----------------|-----|----------------|
|                 | (n)                | virgin ♀       | (n) | virgin ♂       |
| (water)         |                    |                |     |                |
| 27              | 10                 | 3.0 $\pm$ 0.7  | 10  | 2.0 $\pm$ 0.2  |
| 22              | 12                 | 5.0 $\pm$ 0.5  | 12  | 3.0 $\pm$ 0.4  |
| 17              | 11                 | 6.0 $\pm$ 1.0  | 13  | 5.0 $\pm$ 0.4  |
| (water & honey) |                    |                |     |                |
| 27              | 10                 | 15.0 $\pm$ 2.0 | 10  | 12.0 $\pm$ 2.0 |
| 22              | 15                 | 28.0 $\pm$ 3.0 | 13  | 23.0 $\pm$ 2.0 |
| 17              | 12                 | 52.0 $\pm$ 3.0 | 8   | 23.0 $\pm$ 2.0 |

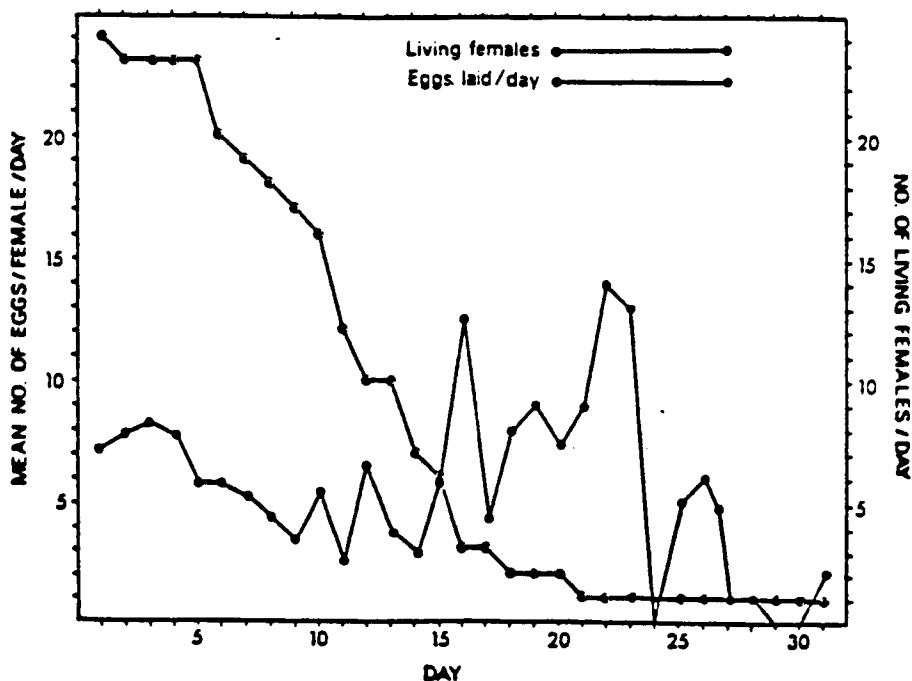


Figure 3. Daily egg deposition and longevity of ovipositing mated ♀ Coccophagus lycimnia.

(Brethes) and C. basilis Comp. (Flanders 1952, Flanders et al. 1968).

## CHAPTER VI

### LARVAL MORPHOLOGY AND DEVELOPMENT OF FEMALE

#### Coccophagus lycimnia (Walker)

##### i. INTRODUCTION

Arrhenotokous development commonly occurs in species of Coccophagus (Flanders 1937, 1967). The mated females are primary parasitoids that oviposit internally on scales insects; whereas, the unmated females are secondary parasitoids that oviposit externally on primary parasitoid larvae that have voided their meconia (Flanders 1937, 1967). Flanders (1937) determined the development and morphology of male larvae of C. lycimnia; however, little information is known on the development and morphology of female larvae. In this study I report the results of tests to determine the morphology and duration of development of female C. lycimnia larvae.

##### ii. MATERIALS AND METHODS

Six inch potted bird's nest ferns, Asplenium nidus L., were subjected to infestation for 24h with Coccus hesperidum L. crawlers. After 24h, the infested ferns were placed into an environmental room maintained at  $27\pm 2^{\circ}\text{C}$ ,  $60\pm 10\%$  RH, and a L:D of 16:8. Once the majority of scales were ca. 1100 to 1500 $\mu\text{m}$  long a portion of scale infested frond was

placed into a 4.5 x 3.0cm petri dish. About 1/3 of the petri dish lid was removed and cotton strips taped on both the lid and the petri dish rim. This methodology kept the frond from being crushed when the petri dish was covered. About 30 adult males and females of C. lycimnia were put into the petri dish, and the fern was placed back into the environmental room. After 24h, the parasitoids were removed and the petri dish was resecured on the frond. Every 12h for 5 days, then every 24h thereafter, 10 or more scales were removed and dissected in Ringer's saline. Measurements were taken with the use of an ocular micrometer and a phase-contrast microscope. Eggs were measured in saline, while larvae and pupae were measured from specimens mounted in Hoyer's mounting medium. Since the mandibles of first and second instars were not easily seen, the larvae of all instars were put into Essig's aphid fluid. After 24h of staining, the larvae were slide mounted in glycerin and the mandibles were measured using an ocular micrometer and a phase-contrast microscope. Larval drawings were made from living specimens placed into saline. Larvae were slowly eviscerated as the saline evaporated from under the coverslip. This procedure rendered all internal structures of the parasitoid larvae easy to observe. Parasitoid pupae were drawn from slide specimens that were mounted in Hoyer's mounting medium. Ovarian eggs were dissected from adult female C. lycimnia in saline.

### iii. RESULTS AND DISCUSSION

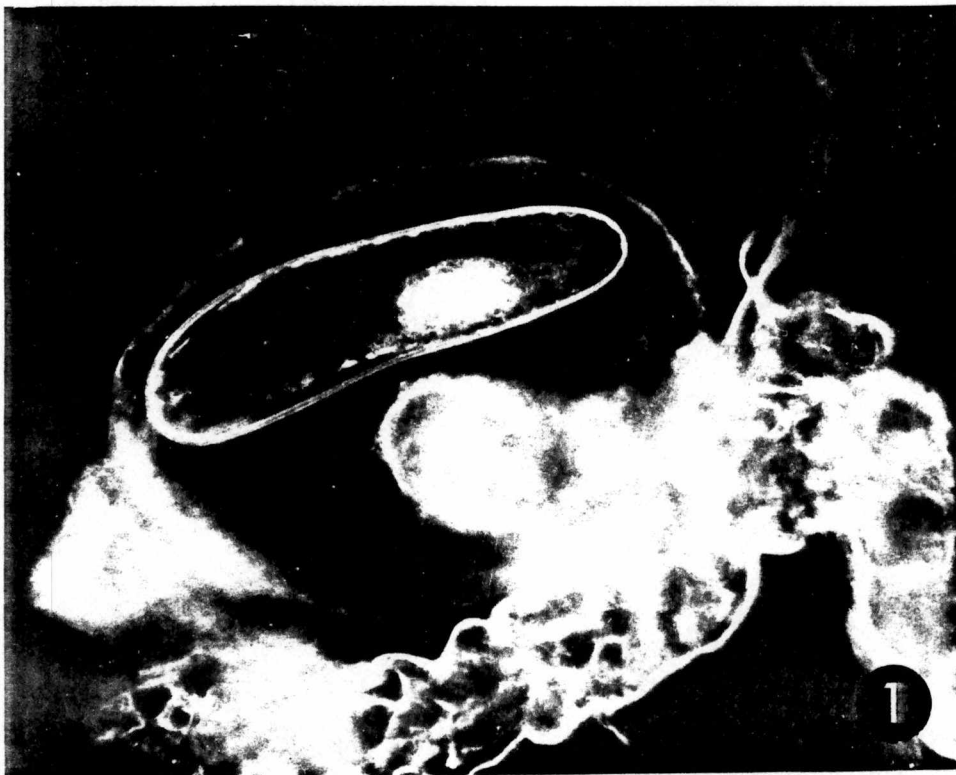
Oviposition behavior of mated female C. lycimnia was similar to other Coccophagus species reported by Cendana (1937). The female paces back and forth over the dorsum of the scale host constantly tapping her antennae on the dorsum of the scale in an alternate fashion. The back and forth motion occurred as few as once or as many as 15 times before she stopped to oviposit or to move on to the next scale. With the antennae and abdomen directed down she began twisting and turning to insert her ovipositor through the dorsum of the scale. The scale sometimes everted its anal plates during this process. Once inserted, she probed with her ovipositor by moving it up and down. The entire process averaged 15 (3-93) seconds. Once completed, she moved on to another scale, but on occasion she fed on the hemolymph exuding from the wound. The ovipositional behavior of C. lycimnia is similar to that described by Cendana (1937) for C. scutellaris. Coccophagus lycimnia deposited her eggs almost exclusively in the midgut region of C. hesperidum (Plate 8, Fig. 1). Those found in the hemolymph were always encapsulated (Plate 8, Fig. 2).

The oval and translucent white eggs dissected from the ovaries of adult females were typical of other Coccophagus spp. (Cendana 1937). When observed through the phase-contrast microscope, eggs were evenly granular internally

PLATE 8. Oviposition site of mated ♀ Coccophagus lycimnia,  
and defense to parasitism by Coccus hesperidum.

Figure 29. Female egg of C. lycimnia in mesenteron of  
of C. hesperidum.

Figure 30. Mated ♀ C. lycimnia egg encapsulated by  
C. hesperidum.



with a smooth chorion. Eggs were  $0.175 \pm 0.003$ mm long and  $0.043 \pm 0.0019$ mm wide.

Eggs dissected from scales 12h after oviposition eggs had an outer shroud of light granular material and an inner dense core of granular material. Eggs were  $0.172 \pm 0.007$ mm long and  $0.0385 \pm 0.004$ mm. The head capsule, mandibles, and some segmentation were visible through the egg chorion of 36h and 48h old eggs. Egg size did not change significantly from 12h to 48h. Eggs were found up to 48h after parasitism (Table 15).

Eggs (Plate 9, Fig. 1a,1b) begin to hatch 36h after parasitism. Larvae were translucent white, 13 segmented excluding the head, and the last abdominal segment pointed. The mandibles, although small, were robust, sickle-shaped,  $0.009 \pm 0.0015$ mm long and  $0.005 \pm 0.0002$ mm wide. The head capsule was  $0.038 \pm 0.001$ mm wide. The tracheal system consisted only a simple tracheal loop with no branching.

Larvae grew from  $0.22 \pm 0.03$ mm at 36h to  $0.41 \pm 0.01$ mm after 12d. Although 1st instars were found up to 20 days after oviposition, the mean length of those found after day 12 began to drop. Curiously, the 1st instar stage was present 20 days after oviposition, which was longer than any other stage of development. Cendana (1937) and Flanders (1937) reported a prolonged development time for 1st instars of C. capensis and C. trifasciatus; however, neither gave any explanation for this phenomenon. I believe this

Table 15. Presence of stages of developing ?  
Coccophagus lycimnia in Coccus hesperidum at 27°C.

| Stage      | Time after oviposition (days) |   |   |   |    |    |    |    |    |    |    |    |    |
|------------|-------------------------------|---|---|---|----|----|----|----|----|----|----|----|----|
|            | 2                             | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |
| egg        |                               |   |   |   |    |    |    |    |    |    |    |    |    |
| 1st instar |                               |   |   |   |    |    |    |    |    |    |    |    |    |
| 2nd instar |                               |   |   |   |    |    |    |    |    |    |    |    |    |
| 3rd instar |                               |   |   |   |    |    |    |    |    |    |    |    |    |
| pupa       |                               |   |   |   |    |    |    |    |    |    |    |    |    |
| adult      |                               |   |   |   |    |    |    |    |    |    |    |    |    |

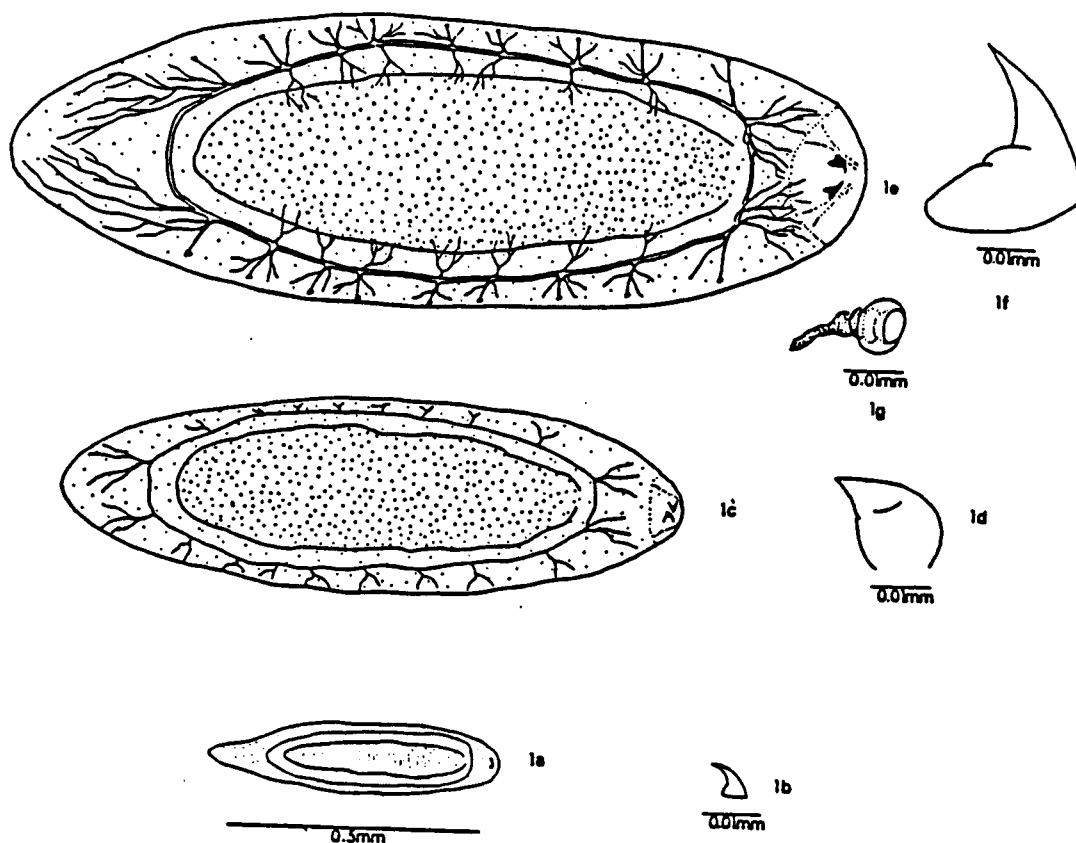


PLATE 9. Larval morphology of ♀ Coccophagus lycimnia.

Figure 1a. Internal structures of 1st instar.

Figure 1b. Mandible of 1st instar.

Figure 1c. Internal structures of 2nd instar.

Figure 1d. Mandible of 2nd instar.

Figure 1e. Internal structures of 3rd instar.

Figure 1f. Mandible of 3rd instar.

Figure 1g. Spiracle of 3rd instar.

phenomenon is explained through the understanding of the parasitoids unusual and complex life history. Flanders (1937) reported that C. lycimnia developed arrhenotokeously. The virgin females were secondary parasitoids that deposited haploid eggs externally on primary parasitoid larvae; mated females were primary parasitoids that deposited diploid eggs internally on coccid hosts. Later, Flanders (1967) explained that this type of developmental sex difference in the aphelinids evolved to reduce trophic pressure and competition on host species. To facilitate the survival value of autoparasitism, Flanders (1967) stated that early mating of virgin female parasitoids was necessary. Early mating could be accomplished if the longevity of the female exceeded the developmental time for males, if hyperparasitization of other species of parasitoids occurred, or if a difference in developmental rates of the female larvae occurred (Flanders 1967). The final result being synchronous emergence of males and females. These criteria are all met by C. lycimnia, as shown from tests I have conducted as well as by observations by Ruben and Beirne (1975).

Second instars (Plate 9, Fig. 1c-d) were found from day 6 to day 20 after oviposition (Table 15), and averaged  $0.68 \pm 0.06$  mm long and  $0.20 \pm 0.01$  mm wide. They were morphologically similar to the first instars except tracheal branching was evident, and mandibles, although

larger, were less sclerotized and more rounded basally. Mandibles were  $0.021 \pm 0.001$  mm long and  $0.012 \pm 0.001$  mm wide. The head capsule measured  $0.095 \pm 0.004$  mm wide. This stage of development also endured for a considerable time; however, I believe this was due to the variable growth rates of the first instars.

Third instars (Plate 9, Fig. 1e-g) were found from day 10 to day 16 (Table 15), and averaged  $1.26 \pm 0.2$  mm long and  $0.36 \pm 0.016$  mm wide. The head capsule increased to  $0.15 \pm 0.003$  mm wide. Mandibles increased to  $0.032 \pm 0.001$  mm long and  $0.022 \pm 0.001$  mm wide, and resembled the heavily sclerotized, sickle-shaped mandibles of the first instar. Branching of the tracheal trunk was much more extensive than in the second instar, and spiracles were present on segments 2 to 10. Spiracles were gobular-shaped, with three smaller swellings between it and the tracheal branch (Plate 9, Fig. 1g).

In the third instar, a membranous sheath was found around the larvae. This phenomenon was first observed by Timberlake (1913) who reported that C. lunulatus Howard pupated in its last larval instar exuvia as a means of protecting it from the fluids of the still living host. Flanders (1938) found many endoparasitic chalcidoid larvae produced a membranous sheath around them during the final instar, and reported that it was not the last larval exuvia, but was formed of materials secreted by several

glands present in the final instar. These glands consisted of a pair of labial glands, which empty their secretions into the buccal cavity, and three ileac glands which empty secretions into the hindgut. Wright (1986), who agreed with Flanders (1938), reported a membranous sheath was formed by Encyrtus saliens Prinsloo and Annecke. She reported that the sheath could not be the last larval exuvia because mouthparts could not be found on the sheath, the sheath formed late in the final instar, the last larval exuvia could be removed from inside the sheath after pupation, and glands similar to those reported by Flanders (1938) were found upon dissection of the final instar. Flanders (1938) reported that some Coccophagus spp. pupate in the dead host and the delicate sheath was destroyed as the contents dry. This also occurred during the development of C. lycimnia. Although the last larval exuvia could not be removed from within the sheath because it was destroyed as the contents of the dead host dried, formation of the sheath was found late in the final instars development and mouthparts could not be found on the sheath when examined. Additionally, Flanders (1938) reported that ileac and labial glands were present in Coccophagus. Although attachments of the host trachea with the sheath were not apparent, trachea were found closely associated with various regions of the sheath. Therefore, these findings support earlier findings by

Flanders (1938) that the sheath is formed from the ileac and labial glands late in the third instar.

The first appearance of pupae (Plate 10, Fig. 2a-b) occurred on day 11, and were found up to day 25 (Table 15). They were 1.1 mm long, and 0.4 mm wide. Pupae were well formed and all external features were easily seen. Pupae were always situated within the mummified host with its head directed posteriorly and ventrally to the host, and meconial pellets, usually nine, settled around the anterior third of the mummified host (Plate 10, Fig. 2a).

Adults began to emerge 15 days after the initial oviposition period, and continued to emerge up to 27 days after oviposition (Table 15). Upon ecdysis, adults always chewed a hole in the posterior third of the dorsum of the host to escape.

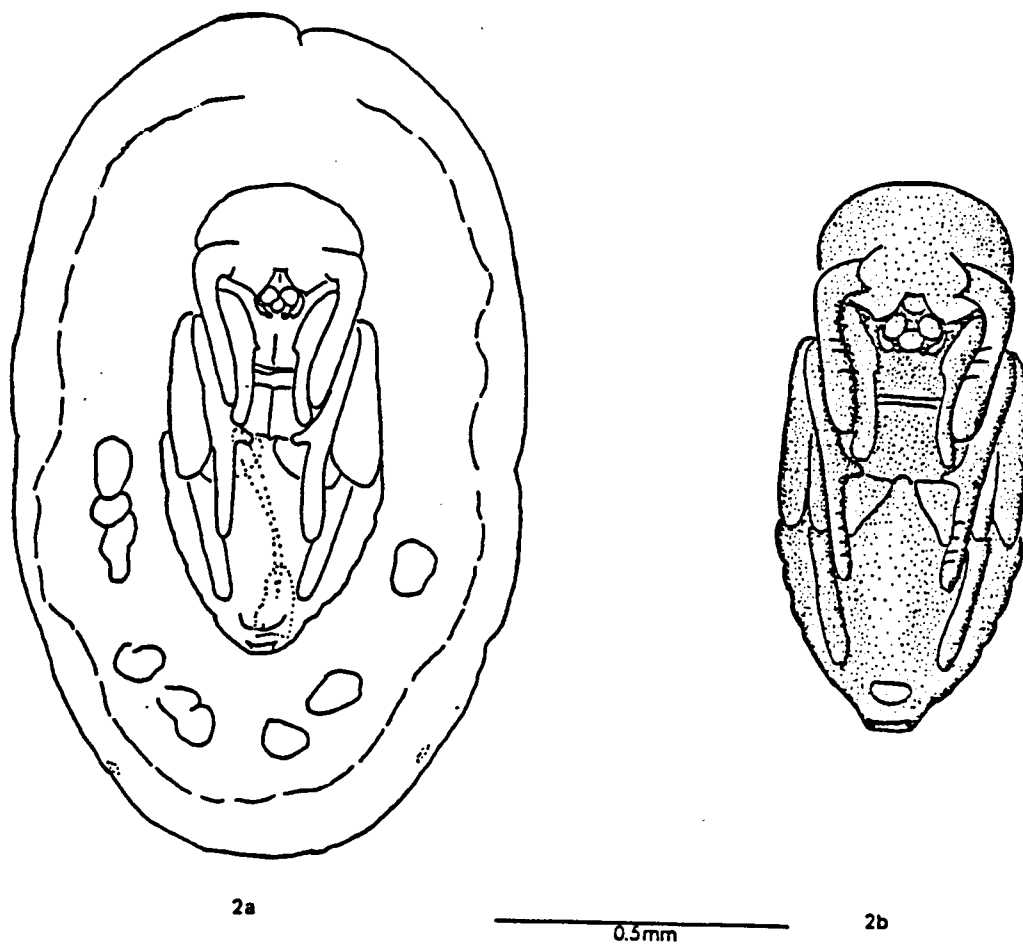


PLATE 10. Pupal morphology of ♀ Coccophagus lycimnia.

Figure 2a. Pupa and meconial pellet position of ♀ C. lycimnia in C. hesperidum.

Figure 2b. External morphology of ♀ C. lycimnia.

## LIST OF REFERENCES

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