SCIENTIFIC NOTE: ON THE BIOLOGY OF MOTHS THAT FEED ON *ERYTHRINA* IN FLORIDA

Andrei Sourakov
McGuire Center for Lepidoptera and Biodiversity, Florida Museum of Natural History, University of Florida, Gainesville, FL 32611, asourakov@flmnh.ufl.edu

Abstract – New studies on the life histories of erythrina leafroller *Agathodes designalis,* and erythrina borer *Terastia meticulosalis* (Crambidae), conducted in Florida, complement previous literature accounts. Specifically, oviposition, egg morphology, survival of larvae, and pupation behavior of these two closely related species are discussed. Another unrelated micro-moth species - erythrina leafminer, *Leucoptera erythrinella* (Lyonetiidae) - also uses coral bean as its hostplant, utilizing this resource in a manner that minimizes interspecific competition witht the abovementioned crambids. New studies on life history of *L. erythrinella* are presented, including illustrations of the immature stages, and sexual dimorphism.

Key words: anatomy, cocoon building, coral bean, Crambidae, ecology, egg, immature stages, larva, Lepidoptera, Lyonetiidae, morphology, niche partitioning, pupa, sexual dimorphism

Last year, I proposed in a publication in this journal that niche partitioning occurred during the course of co-evolution of two closely related crambid moths, *Agathodes designalis* Guenée, 1854 and *Terastia meticulosalis* Guenée, 1854 (Sourakov 2011). Even though I have already illustrated larvae and pupae of these two species in that earlier paper, much of their life history remained unknown. Recently, by keeping several individuals of the reared moths alive in captivity, I was able to obtain eggs of *T. meticulosalis*. I then also located them in the wild. Equipped with the knowledge of their general appearance, I was able to locate eggs of another species, *A. designalis*, and rear larvae. As a result, eggs of both species are illustrated below using light and scanning electron microscopy (SEM). I was also able to find pupae of *T. meticulosalis* in the wild. At the same time, I completed the rearing to the adult stage of the larvae of the overwintering *A. designalis*

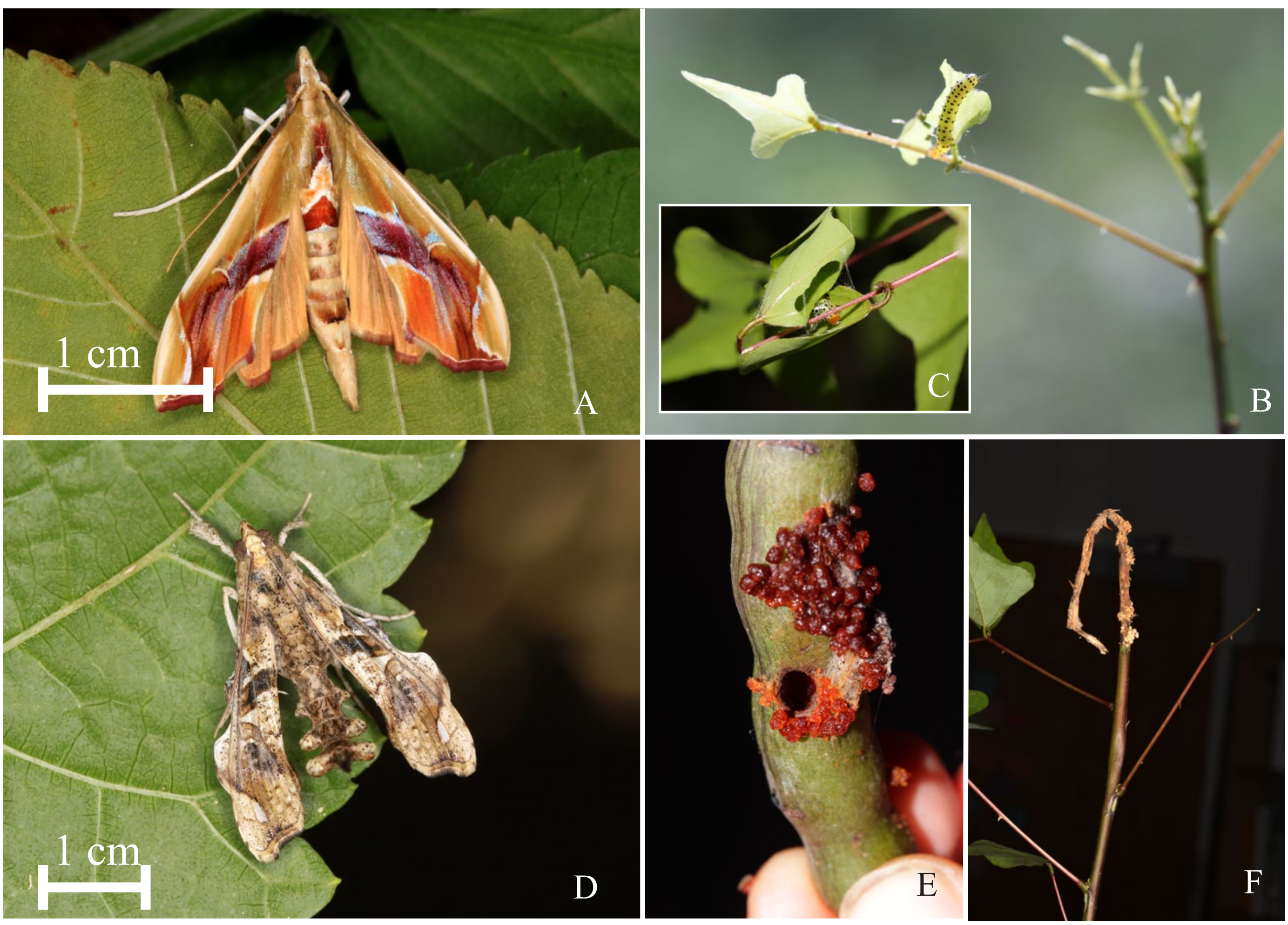


Fig. 1. (A-C) Erythrina leafroller, *Agathodes designalis*: (A) Adult, (B) 3rd instar larva defoliating apical leaves of *Erythrina herbacea*, (C) Mature larva inside a nest that it makes by folding and/or stringing together one or more *E. herbacea* leaves; (D-F) Erythrina borer, *Terastia meticulosalis*: (D) Adult, (E) Exit hole in a pod of *E. herbacea* with larval excrements on the outside, (F) Tip of *E. herbacea* shoot infested by a larva of *T. meticulosalis*, which burrows down the stem while expelling its excrements and stringing them together on the outside.

Fig. 2. Erythrina leafminer, *Leucoptera erythrinella*: (A) Adult male, dorsal view, (B) Adult female, ventral view, (C) Infested coral bean plant: each discolored leaf produces one or two *L. erythrinella* individuals; (D) Close-up of the mines.

generation, which remained as diapausing prepupae during the winter. Hence, in the present note, I am able to rectify the lack of knowledge about how these species oviposit, pupate, and diapause. Finally, I illustrate the life history of the only other moth species whose larvae specialize on *E. herbacea* in north-central Florida: the erythrina leafminer, *Leucoptera erythrinella* Busck, 1900 (Lyonetiidae: Cemiostominae). Methods and field study locations are the same as in Sourakov (2011).

***Terastia meticulosalis* Guenée, 1854**

In May-June 2012, larvae of *T. meticulosalis* (Fig. 1D) were collected and reared from pods of the coral bean that showed signs of infestation (Fig. 1E, F). The resulting adults were fed sugar solution three times a week and were kept alive in a jar, in which they were provided with an *E. herbacea* stem cuttings. Female moths that were several days old were dissected, but had no eggs inside them. However, judging by dissecting older females, after ca. 10 days, eggs were formed. From this I conclude that feeding and/or mating are required by *T. meticulosalis* to develop eggs.

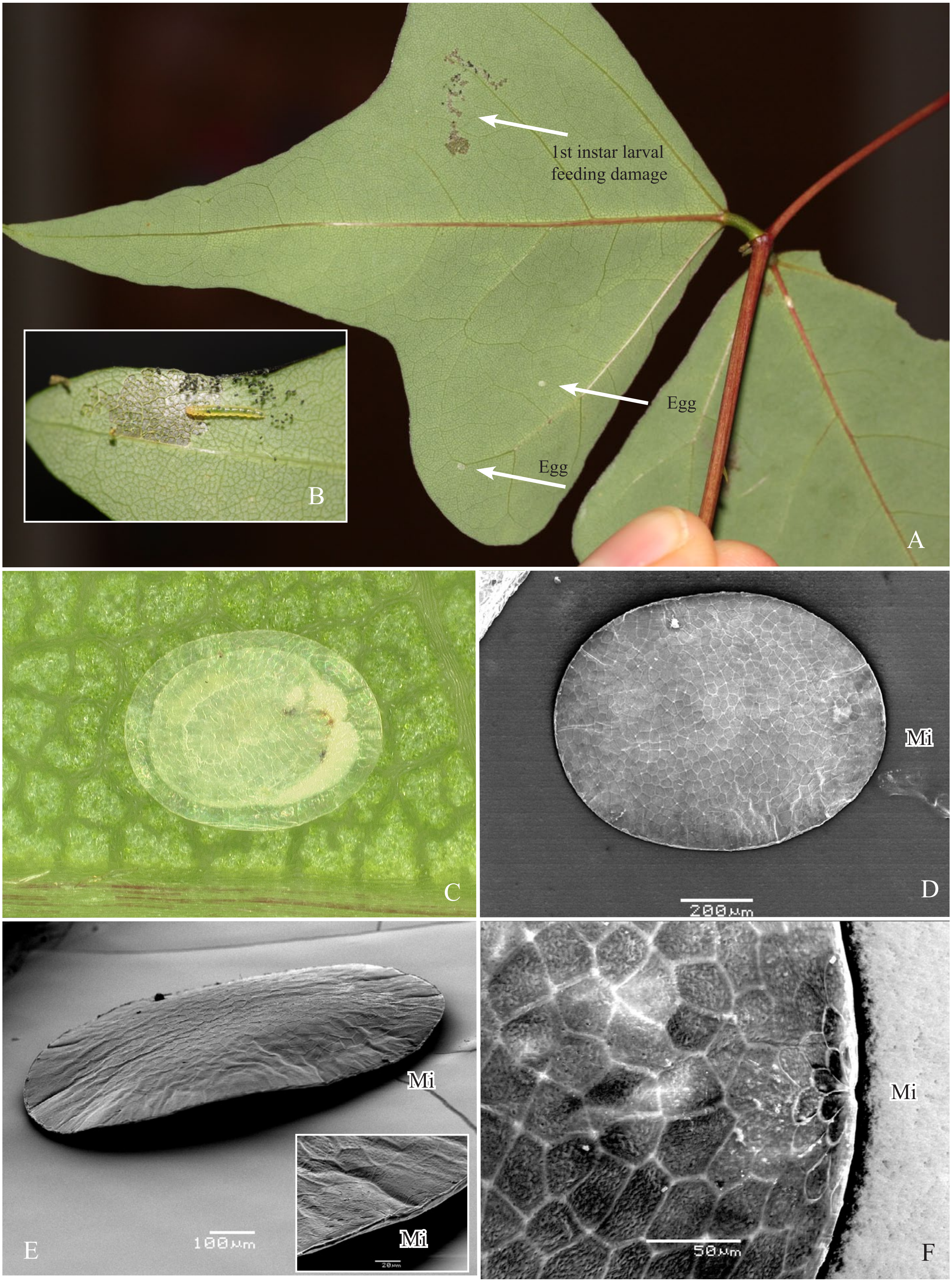
An egg from the captive moths was finally obtained in mid-July, upon which more eggs were also found in the wild. Eggs are laid singly into the leaf axill (Fig. 3A). They are translucent-white and delicate (Fig. 3B, C). The larva most likely comes out through the ventral surface, tunneling directly into the plant stem. SEMs reveal a regular reticulated structure of the dome-shaped egg (Fig. 3D), with the micropyle located dorso-laterally.

In July 2012, I observed that most of the tops of the shoots of *E. herbacea* became infested and heavily damaged by either *T. meticulosalis*, which were dominant, or *A. designalis*. At this point, some shoots became infested a second time, with infestation occurring in the middle or even in lower parts of the stems. Presumably, because the stems become hard and their tips are already destroyed, tiny first instar larvae burrow through leaf petioles, where, I suppose, the eggs are laid.

One of the reared adult moths was kept alive for approximately three weeks and maintained its vigor, at which point feeding was terminated. These moths were observed to be good fliers, exhibiting hovering flight similar to that of Sphingidae. In addition to the protection from predators, parasitoids and many abiotic mortality factors gained from larval endophagous feeding habits, the longevity of *T. meticulosalis*, as well as its flight abilities, might explain why they are so

Fig. 3. Egg of erythrina borer, *Terastia meticulosalis*, which is laid in the leaf axill of *E. herbacea*; (A) Egg on a young shoot; (B, C) same egg photographed with auto-montage system; (D) Same, scanning electron micrograph.

Opposite page: Fig. 4. (A) Eggs and first instar larvae of erythrina leafroller, *Agathodes designalis*, located on the underside of *E. herbacea* leaves; (B) first instar larva, close-up; (C) Larva inside the egg; (D) SEM of the egg, dorsal view; (E) SEM lateral view and a close-up of the micropyle (Mi); (F) Close-up of the egg surface around micropyle.


1st instar larval feeding damage
Egg
Egg
B
A
C
Mi
200µm
D
Mi
Mi
100µm
20µm
E
Mi
50µm
F

efficient in infesting a large number of *E. herbacea* plants, and why all members of the genus *Terastia* are so successful worldwide as pests of various *Erythrina* species (see references within Sourakov 2011).

Until recently, in my studies of various aspects of the ecology of *T. meticulosalis*, I obtained all pupae by raising wild-collected larvae in captivity. During pupation, the full-grown larvae exited the pods or stems in which they fed and made a double-layered cocoon amidst tissue paper provided to them. This may indicate that the larvae are pupating in the leaf-litter. However, during the 2012 flowering season of *E. herbacea*, I found several *T. meticulosalis* pupae inside dried-up flowers at the end of the stems that had been killed off by the respective larvae (Fig. 7A). Later in the season, when flowering was over, a pupa of *T. meticulosalis* was found inside a folded leaf of *E. herbacea* (Fig. 7B, C), in a manner similar to the pupation of *A. designalis* (Fig. 7E, F). Hence, despite differences in oviposition (see below) and larval feeding behavior, the ways in which these two species pupate are quite similar. The strongly pronounced double nature of the cocoon of *T. meticulosalis* (Fig. 7C, D) also exists, but is much less pronounced, in the much thinner cocoon of *A. designalis* (Fig. 7F, G).

***Agathodes designalis* Guenée, 1854**

Equipped with the knowledge of the size and appearance of *T. meticulosalis* eggs (see above), I was able to easily locate eggs of *A. designalis* in the wild. In fact, in mid-July 2012, they were plentiful on the undersides of the leaves (usually in the upper third of the shoots). Eggs were mostly found in pairs or in triplets (Fig. 4A) (this corresponds to my observations of mature *A. designalis* larvae, which are also frequently distributed 2-3 individuals per plant). Eggs of *A. designalis* are white and translucent to the extent that the larva, when formed inside, becomes clearly visible (Fig. 4C). Unlike the eggs of *T. meticulosalis*, the eggs of *A. designalis* are flat and oval-shaped (Fig. 4E). The micropyle is located not mid-dorsally, as it is in most Lepidoptera eggs that I have encountered, but laterally, at the narrow ridge that joins the dorsal and the ventral egg surfaces (Fig. 4D, F).

Hatched eggs of *A. designalis* were frequently found in association with 1^{st}-2^{nd} instar larvae. They were not described in Sourakov (2011), because I was unable to find them - they proved to be cryptic on the plant; unlike more mature larvae, they do not make nests by folding the leaf, and they do not make holes in the leaves, but instead feed on the underside by consuming only the lower cuticle and the mesophyll, without damaging the upper cuticle (Fig. 4A, B). It took ca. 3 weeks for one of these larvae to reach the pupal stage under the laboratory conditions at ca. 75°C. The first 2012 adults of *A. designalis* (Fig. 1A) resulted from larvae that went into diapause inside cocoons in October 2011, but pupated only in March 2012, emerging two weeks later.

Compared to 2011, where I found only a few *A. designalis* larvae during July-September, the *E. herbacea* infestation of 2012 by this species was more extensive. In 2011, the two species partitioned the habitat, with larvae of *T. meticulosalis* and *A. designalis* never sharing the same plant. However, by July 2012, every shoot not infested by *T. meticulosalis* was almost guaranteed to be occupied by *A. designalis* larvae even on the same plant (although almost never on the same shoot), so the competition for the unoccupied shoots must have become very intensive. Larvae of *A. designalis* fed on the tender upper leaves when young (Fig. 1B), and as they matured, made nests inside older and lower leaves (Fig. 1C). Both species proved to be prolific to a degree where they can cause a lot of damage to individual *Erythrina* plants and reach high density. The competition for larval food has likely, according to theory, caused these two species to evolve different life styles, leading to the observed partitioning of food resources.

Endophagous vs. exophagous feeding: benefits and shortfalls

As described previously (Sourakov 2011), in April-June the larvae of *A. designalis* feed in silk shelters that they build among flowers and flower buds on an inflorescence of *E. herbacea*, while *T. meticulosalis* larvae may feed inside the stem supporting such inflorescences. The endophagous feeding of *T. meticulosalis* may provide a better shelter from predators and parasitoids, as well as from the heat. In 2012, however, after an unusual week of constant heavy rains due to a tropical storm, I observed that there may be an advantage to the exophagous feeding habits of *Agathodes*. In that instance, a number of *T. meticulosalis* larvae were found expelled from their tunnels by the rain water, drowned, and consumed by ants (Fig. 8B). On the same rain-soaked plants, the *A. designalis* larvae appeared perfectly intact (Fig. 8C).

***Leucoptera erythrinella* Busck, 1900**

Finally, when talking about "erythrina moths" in north-central Florida, one should, in addition to erythrina borer and erythrina leafroller discussed above, mention the third moth species that exclusively uses *E. herbacea* as a host plant: erythrina leafminer, *Leucoptera erythrinella*. Even though this moth is 10-20 times smaller than the other two (Fig. 2A, B), it is a formidable competitor for the food resource. Unlike the other two moth species, the larvae of *L. erythrinella* feed inside the leaves, making elaborate and characteristic mines (Fig. 2D), which from a distance appear as discolorations (Fig. 2C).

When an infested plant was discovered, the majority of leaves on such plants were affected (Fig. 2C), perhaps due to the fact that these tiny Lepidoptera have a slow hovering, usually vertical, flight, which perhaps limits their dispersal abilities. To some extent *L. erythrinella* temporally partitions resources with respect to the other two erythrina moth species, with this leafminer infesting plants later in the season (August—September), when infestations by *T. meticulosalis* and *A. designalis* begin to decline.

Needless to say, the eggs of *L. erythrinella* are much (ca. eight times) smaller than those of the other two erythrina moths (Fig. 5). Comparable in size to the leaf stoma cells (Fig. 5C), they are translucent to the degree of transparency when laid (Fig. 5 B) and appear to the naked eye as tiny dust particles on the leaf surface. The micropyle of the dome-shaped egg (Fig. 5C, D) is located dorso-laterally. The egg is covered with a reticulated hexagonal structure that can be observed using SEM. Eggs illustrated here were obtained from moths in captivity; thus it is unclear how many of them are laid per leaf

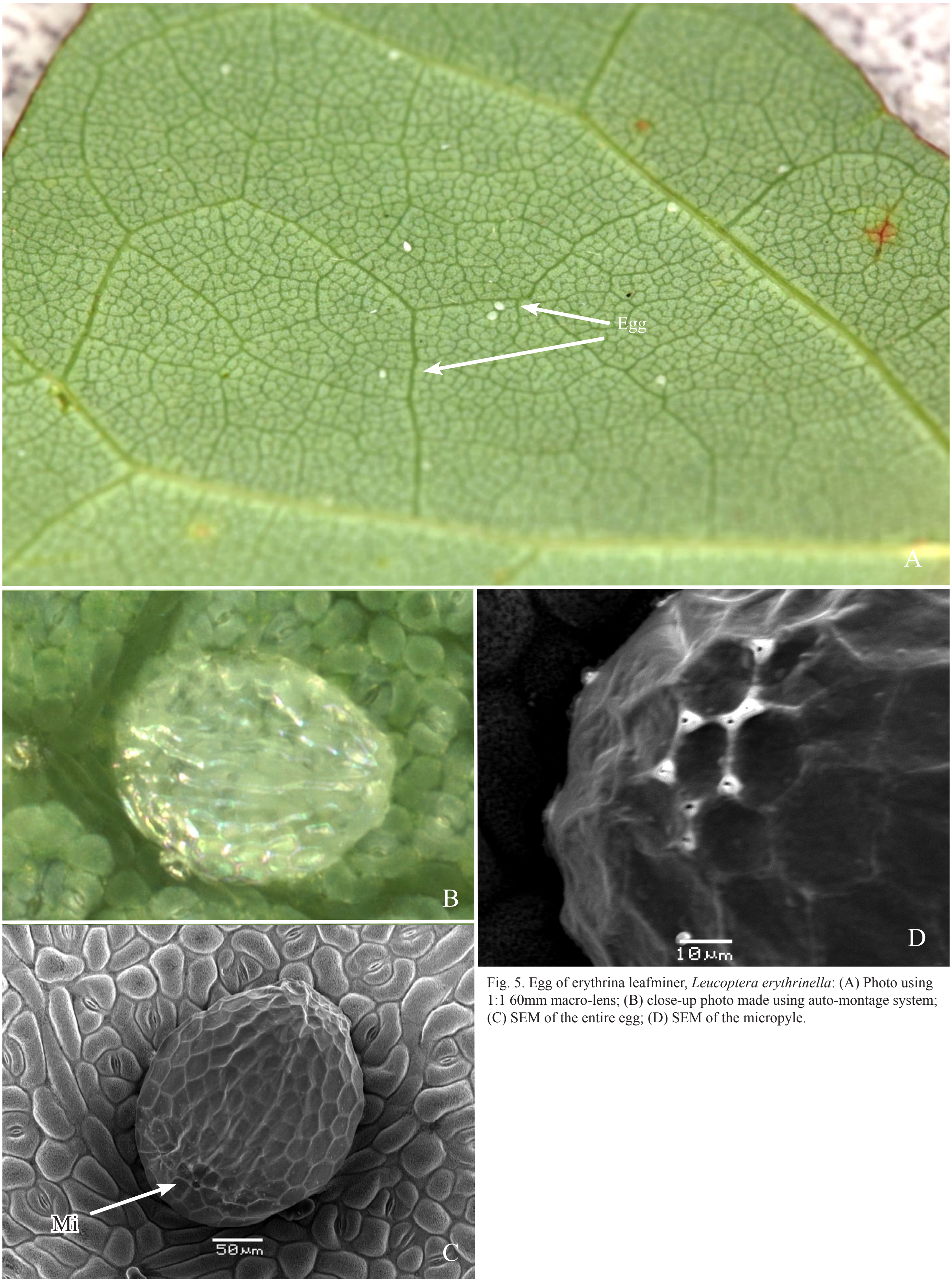


Fig. 5. Egg of erythrina leafminer, *Leucoptera erythrinella*: (A) Photo using 1:1 60mm macro-lens; (B) close-up photo made using auto-montage system; (C) SEM of the entire egg; (D) SEM of the micropyle.

Fig. 6. Stages of development of erythrina leafminer, *Leucoptera erythrinella*. **Immatures:** (A, B) Movement of a mature larva that exited the leaf mine prior to pupation; (C) Larva spinning a cocoon, which is always found on the underside of the leaf; (D) Cocoon with a pupa inside; (G) Pupa, cocoon removed, next to the head of #3 entomological pin. **Adults:** (E, I, L) females; (F, H, J) males; (K) close up of sclerotized male genitalia.

Opposite page: Fig. 7. **(A-D)** Pupation strategies of erythrina borer, *Terastia meticulosalis*: (A) In the spring, cocoons were found inside inflorescences partially or completely destroyed by larval feeding; (B-C) In the summer, cocoons were found in folded leaves; (D) Cross-section of a cocoon showing that its outer layer is loose; normally, the cocoon is firmly attached to the surrounding substrate, while the denser inner layer protects the pupa; **(E-G)** Pupation of erythrina leafroller, *Agathodes designalis*: (E) Cocoon is normally spun inside a rolled leaf; (F) When opened, the inner cocoon is usually torn, exposing the pupa; (G) cross-section revealing double-layered nature of the cocoon.

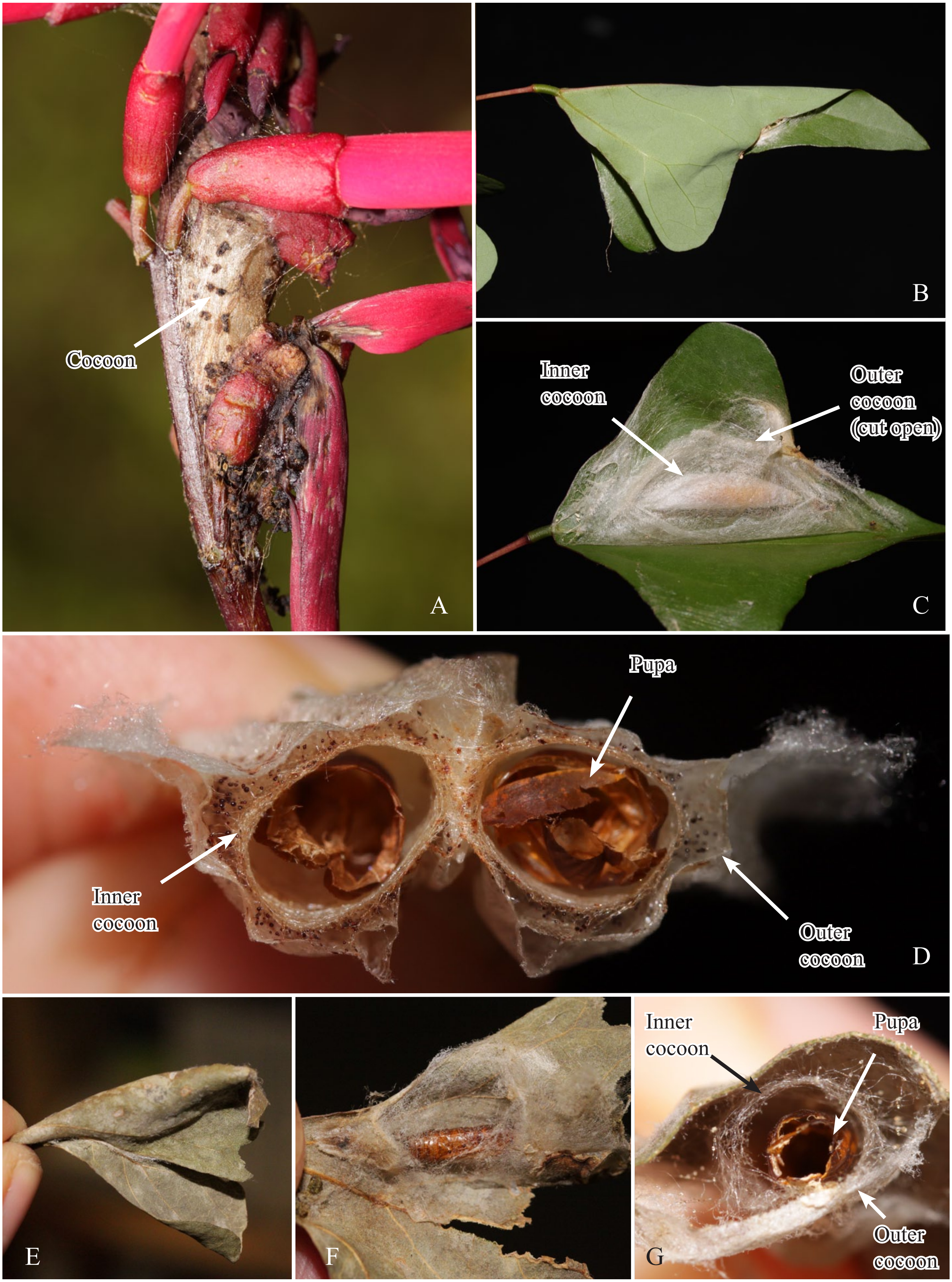

Cocoon
A
B
Inner
cocoon
Outer
cocoon
(cut open)
C
Pupa
Inner
cocoon
Outer
cocoon
D
E
F
Inner
cocoon
Pupa
Outer
cocoon
G

Fig. 8. The larval mortality of erythrina moths following submergence by rain water: (A) The inflorescence of *Erythrina herbacea* in May, 2012 in Gainesville, FL; (B) After prolonged heavy rains, larvae of *Terastia meticulosalis* were found expelled from their tunnels, appearing to have drowned. In this photo, dead larvae are consumed by ants; (C) Larvae of *Agathodes designalis* survive flooding thanks to the silk shelters that they construct among flowers.

in the wild. Typically, only one or two mines were found on a single leaf. Busck (1879), in the original description of this species, which he collected in Florida, indicates that "…Egg is laid on underside of leaves of *Erythrina herbacea*, and the mine begins on the upper side as a short serpentine track, but soon broadens out in a large irregular blotch, often obliterating the early part of the mine."

Larvae that exit the mine to pupate at the surface (Fig. 6A, B) are shaped like larvae of cerambycid beetles, and move like maggots. The pupa is cream-white (Fig. 6E) and is located inside a "hammock", which Busck described as "being placed on the outside of the mine on the leaf in a glistening white oblong cocoon spun under an equally showy white bridgework of longitudinal silken bands" (Fig. 6C, D). In my experience, pupation can occur on the same leaf as the mine, as Busck indicated, but more often cocoons are found on another leaf away from the mine.

Busck describes adults from five bred specimens as follows: "Face, head, eyecaps and thorax shining pure white. Forewing shining white; from middle of dorsal margin outwards to fold an oblique streak of sparse, fuscous scales, opposite which is a small indistinct costal streak of the same hue, together forming a V with the point toward apex. Three indistinct fuscous streaks within costal cilia and a large patch of somewhat darker fuscous scales on the dorsal edge of the wing near apex...". He makes no mention of sexual dimorphism that I observed. Adults that I bred fall into two phenotypes: females show the dorsal black pattern on forewings, as described by Busck (who did not attribute gender to his five specimens), plus a dark patch on the thorax and tornus of the forewing (Figs 2A & 6E, I), while males are snow-white, with the exception of a narrow chocolate-colored tornus (Fig. 6F, H), black eyes that are hidden dorso-laterally under white eyecaps (Fig. 6I), and black sclerotized valvae equipped with teeth-like structures (Fig. 6K).

Supplementary Information: The video of cocoon spinning by *Leucoptera erythrinella* larva can be viewed at: http://www.youtube.com/watch?v=gaec4Sz6BOw

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