Novel Descriptions of Immature Stages of the Forestry Insect Pest, *Yponomeuta meguronis* (Lepidoptera: Yponomeutidae), with New Records of Its Natural Enemies

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Abstract: The genus *Yponomeuta* is widely known as a forestry insect pest group; however, it is extremely difficult to identify it at the species level because of its small size and morphological complexity. Thus far, only a few major species and host plants, as well as natural enemy information, are known through European research within the limited eastern Palearctic region. In this study, *Yponomeuta meguronis* Matsumura is revealed to be a severe forestry insect pest for *Euonymus japonicus* Thunb. (Celastraceae) in Korea, which constitutes part of the western Palearctic region. We observed that numerous tiny larvae caused serious damage to its leaves and partially or entirely covered the tree by making communal silk webs. To rapidly and accurately identify this insect pest in the future, new descriptions of immature stages, including larva and pupa, were provided, along with their adult forms, based on ecological photographs and morphological illustrations. Two natural enemies of *Y. meguronis* were also recognized for the first time in this study: *Herpestomus brunnicornis* (Gravenhorst) (Hymenoptera: Ichneumonidae) was revealed as a parasitoid, and *Xanthandrus comtus* (Harris) (Diptera: Syrphidae) was presented as a predator.

Keywords: forestry pest; immature stages; *Yponomeuta*; parasitoid; predator; taxonomy

1. Introduction

The genus *Yponomeuta* Latreille, also known as small ermine moths, is one of the largest genera of the family Yponomeutidae (Lepidoptera: Yponomeutoidea), comprising approximately 75 species worldwide [1,2]. The *Yponomeuta* is widely known to be an insect pest group in forests, orchards, and horticulture: *Y. malinellus* (Zeller) was introduced into the United States in the early 19th century and has spread worldwide as an apple and cherry insect pest [3]; *Y. cagnagella* Hübner is a specialist on *Euonymus europaeus* L. (Celastraceae); *Y. padellus* (Linnaeus) is oligophagous on a number of Rosaceae plants [4]; and *Y. cagnagella* is known as a euonymus webworm in North America [5], and is also a common pest of European ornamental trees and shrubs [6]. According to recent studies, they are mainly distributed in Palearctic regions [2] but have spread to Holarctic regions. Of them, 14 species have been reported in Korea to date by several researchers [1,7–10]. The genus *Yponomeuta* usually has complicated black dot variations on the forewing, but it can be characterized by the following: (i) a forewing with 12 veins and chorda, and pterostigma that is well-developed from near the 1/2 base to the distal area of Radial vein 1(R1), Median vein 3 (M3) and Cubitus anterior vein 1(CuA1) which connate to short-stalked; (ii) the male genitalia of uncus is usually a quadrate plate; socius is curved outwardly with some sparse hair-like setae, with one or two thorns at the apex; gnathos ventral plate

with a pair of porrect processes which are sometimes covered with spinules; semioval, elongated oval or triangular valva with a rounded outer margin; long and narrow sacculus, with some spinules at the discal margin; moderately long saccus which is dilated at the terminal; aedeagus longer than the saccus; cornuti composed of four distinct spines and two spines anteriorly, with many small spinules; (iii) female genitalia of papillae anales are semioval with hair-like setae; the intersegmental membrane between the papillae anales and eighth segment is short or extended slightly; apophyses anteriores is branched and similar length to the apophyses posteriors; lamella postvaginalis produces a pair of semioval pads with erected hair-like setae; ostium bursae is ringed and spinulated; sclerotized antrum, usually cup-shaped; ductus bursae is long, membranous and partially granulose; and the corpus bursae is oval or circular without signum [11,12]. Although their morphological characteristics have been well organized by many yponomeutid taxonomists, most of them are limited to the adult morphology. Most pests damage plants when they are larvae in the field; therefore, knowing the adult morphology alone makes it difficult to identify insect pests.

We observed that several larvae of the yponomeutids feed gregariously by making communal silk webs on a colony of *Euonymus japonicus* Thunb. They can cause extensive defoliation of the trees, sometimes entirely, but often partially (Figure 1).

Yponomeuta are forestry insect pests that generally have limited host ranges; therefore, steady research on their host plants is required, although most of this has been conducted by European researchers. In a previous study, Menken et al. [13] indicated that *Yponomeuta* is a monophagous genus feeding on Celastraceae, Rosaceae, or Salicaceae families, and they hypothesized that *Yponomeuta* evolved from an ancestral association with Celastraceae through allopatric speciation. Except for a few species, such as *Y. gigas* (Rebel), which feeds on *Salix* and *Populus*, most European *Yponomeuta*, such as *Y. cagnagella*, *Y. irrorellus* Hübner and *Y. plumbellus* (Denis & Schiffermüller), feed on Celastraceae, mainly on *Euonymus*. Some studies also analyzed a wide range of parasitoids of European *Yponomeuta* species. Recently, Žikić et al. [14] reported an updated checklist of the parasitoids of *Yponomeuta* species, including *Y. cagnagella*, *Y. evonymella*, *Y. malinellus* and *Y. padella*. They presented 15 parasitoid species of 6 hymenopteran families, Ichneumonidae, Encyrtidae, Eulophidae, Eurytomidae Braconidae, Pteromalidae, and 1 dipteran family, Tachinidae. Unlike in Europe, research on *Yponomeuta* is poorly conducted in East Asia, which is a western part of the Palearctic region. Only Moriuti [11] has assessed Asian Yponomeutids, hypothesizing that they may be potentially serious and destructive insect pests, reported that *Y. meguronis* Matsumura cause damage to host plants, such as *Euonymus fortuni* in Japan, and also provided information of the genital characteristics of adults.

The aim of this study was to report new descriptions of larva and pupa of the arboreal pest, *Y. meguronis*. Additionally, we newly reported its natural enemies, including a parasitoid, *Herpestomus brunnicornis* (Gravenhorst), and a predator, *Xanthandrus comtus* (Harris). Illustrations for all stages of pest, including adults and genitalia, and two natural enemies, are also presented.

Figure 1. Larva of *Yponomeuta meguronis* on a colony of *Euonymus japonicus* Thunb (personal observation): (**a**) early stages (1–2 instars) of larva dorsally tinged with pale brown; (**b**,**c**) middle to last instar of larvae dorsally tinged with dark gray; (**d**,**e**), larvae making silk webs; and (**f**) larvae and pupa in silk webs.

2. Materials and Methods

More than 150 larvae were collected in southwestern Korea (Chungcheongnam-do (CN), Taean-gun, Sowon-myeon, Uigyang-ri, 977-18, near the Taean Peninsula). For observation of immature stages and emergence into adult, we caught early-stage larvae (1–2 instars) and carried out indoor breeding. The indoor temperature was maintained at 26 degrees, and the humidity was adjusted to approximately 60%, so that the host plants did not dry in the breeding cages (plastic, 60 cm × 60 cm × 80 cm).

To describe the larvae, we boiled the whole body of the larva in 10% KOH for 30–40 min at 70 °C. All materials, including larva, pupa, and adult and natural enemies (parasitoid and predator), were examined under an Olympus SZ61 stereomicroscope and photographed with a DMC 5400 digital camera attached to a Leica Z16 APO motorized microscope. Serial images were combined using Zerene Stacker and digitally retouched using Adobe Photoshop CS6.

For genital and morphological characteristics of adults, we examined dried specimens. All dried specimens were collected from East and West islands (Is. Dokdo, Is. Yongyu) and the eastern inland area (Gyeongsangbuk-do (GB), Uljin-gun, Geunnam-myeon, Gusan-ri, (36°55′52.34″ N, 129°21′32.05″ E). A light screen was established and maintained for 4–5 h. The specimens were collected at the light screen traps with a 200 W mercury vapor lamp and four 20 W UV lamps, and two white screens (2.0 m × 1.5 m) behind the lamp. The collected moths were killed in poison bottles with 30% ammonia water. Genitalia were mounted on the slide after being treated with a method modified from Robinson [15]. All genitalia slides were dissected and subsequently examined under a Leica EZ4 stereomicroscope. Genital photographs were taken with a Leica DM 2500 microscope attached to a Leica ICC50 E.

Terminology (including abbreviations) of immature stages is as follows: Nichols [16], Peterson [17], Stehr [18], Passoa [19] and Albertoni et al. [20]. Additionally, a description of longitudinal black dots series on the forewing of adults by Moriuti [21] was referred to.

3. Results

3.1. Systematic Accounts of Yponomeuta meguronis

Yponomeuta meguronis Matsumura [22]

Hyponomeuta meguronis Matsumura [22]: 6000. Ill. Ins. Jap.: 1098. Type locality. Japan (Honshu, Tokyo).

Hyponomeuta hexabola: Meyrick [23], Exot. Micr. 4(19): 602. Type locality: Japan (Kyushu, Kumamoto Pref. Amakusa).

Yponomeuta meguronis: Inoue [24], Check list Lep. Jap. 1: 38; Moriuti, 1977, Faun. Jap. Ypon. s. l.: 187.

Yponomeuta hexabola: Inoue [24], Check list Lep. Jap. 1: 38.

Yponomeuta hexabolus: Friese [25], Beitr. Ent. 12(3/4): 314.

3.1.1. Diagnosis

A total of 14 species of *Yponomeuta* have been reported in Korea. Of them, *Y. meguronis* is superficially similar to *Y. eurinellus* Zagulajev, but it can be distinguished by the following male genital characteristics: (i) socius with one thorn at the tip; (ii) the aedeagus is much longer than the valva, and (iii) triangular-shaped valva.

3.1.2. Description

- **Larva**; Body (Figure 2a,b): pale brown to dark gray; Pinacula darker than body. Head (Figure 2c–e): round, hypognathous; epicranial suture present, as long as lateral adfrontal suture; adfrontal suture slightly concave after middle part; ecdysial line distinct.
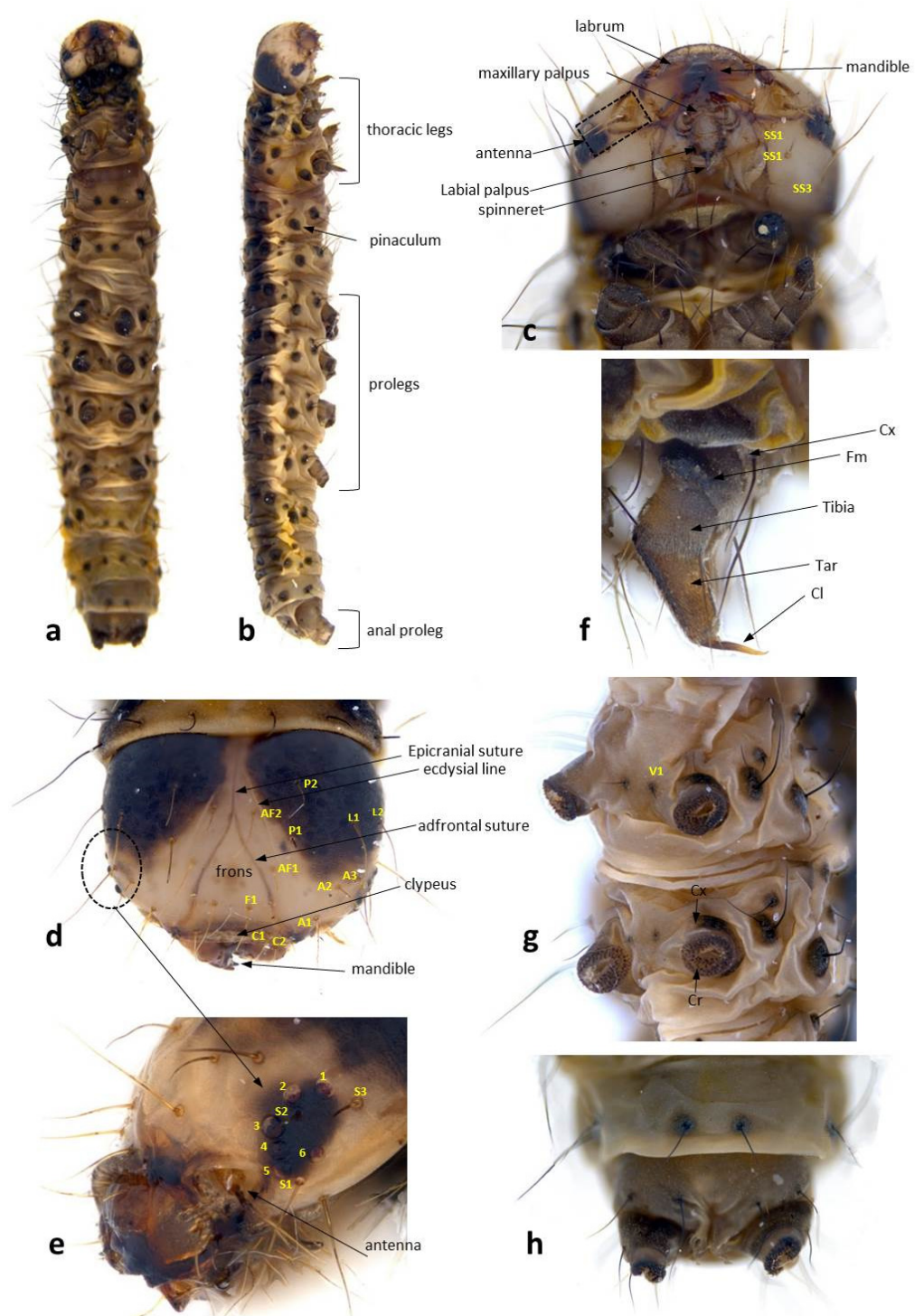
Figure 2. Larva of *Yponomeuta meguronis*: (**a**) ventral view; (**b**) lateral view; (**c**) frontal and ventral view of head; (**d**) frontal and dorsal view of head; (**e**) lateral view of head; (**f**) thoracic leg; (**g**) crochets of prolegs; (**h**) anal proleg. Abbreviation: A, anterior setae; AF, adfrontal setae; C, clypeal setae; F, frontal setae; L, lateral setae; P, posteriodorsal setae; S, stemmatal setae; V, ventral setae; Cx, prothoracic coxa; Cr, crochets.

Six stemae: 1, 2, 3, 4, 5 in a semicircular shape, stema 6 anteroventral to stema 4. Clypeus sclerotized with dark brown posterior margin. Antennae is brown, with three antennomers: basal one wider with one sesilla; the second narrower and extended with five segmented, bearing two sesilla setae: one longer and the other shorter. Maxillary

palpi three segmented, the second segment is rather dark brown. Mandible sclerotized and serrated, bearing two lateral setae (AMS, PMS). Labium with a pair of labial palpus; labial palpus brown, spinneret dark brown. Legs (Figure 2f–h): thoracic leg with femur darker than other segments, protruding, tarsus rather longer than the tibia, claw extended; prolegs four pairs, Cx distinct, Cr triordinal circle; anal proleg one pair.

Chaetotaxy. In cephalic capsule (Figure 2c–e), 18 long and tactile setae, A1, A2, A3, F1, AF1, AF2, P1, P2, L1, L2, S1, S2, S3, C1, C2, SS1, SS2 and SS3; AF2 slightly above apex of frons, AF1 at 1/3 basal part of adfrontal area; between adfrontal suture and ecdysial line; P1 above the AF1, P2 above the AF2; L1 dorsolateral to P1, L2 lateral to L1; six stemmata C-shape positioned, S1 anteroventral to stemma 5, S2 dorsolateral to stemma 3, S3 anteroventral to stemma 1; C1 anterolateral to F1, just above clypeus, C2 next to C1 at end of clypeus; sensilia of maxillary palpus as same length as spinneret; SS1 under the antenna, SS2 anteroventral to stema 5, SS3 is the most distal portion. *Thorax* (Figure 3a): segment T1 bearing 11 pairs of setae, D1, D2, XD1, XD2, SD1, SD2, L1, L2, SV1, SV2 and V1; D1, D2, SD1, and SD2 in prothoracic plate: D1 dorsolateral to D2, SD1 slightly dorsolateral to SD2; XD1 and XD2 before the prothoracic plate. L2 is thinner than L1, L1 in prespiracular pinaculum. SV2 thinner than SV1, SV1 anteroventral to SV2. Segments T2 and T3 with 9 pairs of setae, D1, D2, SD1, SD2, L1, L2, L3, SV1 and V1; D1, D2, SD1 and SD2 in metathoracic plate: D1 and D2 approximate; SD1 anteroventral to SD2, the former thicker than the latter. L1 and L2 in same pinaculum, distal to L3, L2 thicker than L1 and L3. SV1 in a single pinaculum.

Abdomen (Figure 3b–d): Chaetotaxy in segments A1 and A7 with 9 pairs of setae, D1, D2, SD1, L1, L2, L3, SV1, SV2 and V1; D1 and D2 same and approximate. SD1 anteroventral to D1. L1 and L2 thinner than L3: L1 and L2 approximate, L3 distal to the formers, each in pinaculum. SV1 is thicker and anteroventral to SV2. Segments A2-A6 with 10 pairs of setae, similar to A1, but SV3 is present between SV1 and SV2. Segment A8 with 8 pairs of setae, similar to A1, but SV2 and SV3 absent. Segment A9 with 8 pairs of setae, similar to A1, but SD1 thinner than others, L3 absent. Segment 10 with 8 pairs of setae; XD1 before D1, XD1, D1 and D2 almost in a same line. L1 lateral to L2. SV1 posterodorsal to V1.

- **Pupa** (Figure 4); Adecticous, obtect; cylindrical, gradually narrowed posteriorly; cuticle light brownish yellow. Caput: Eyes moderate. Epicarania suture absent. Vertex subrectangular, wide laterally. Lateral invagination anterior to antenna. Antenna curved to medial body, extending to A5, before ending of metathoracic legs. Fronto-clypeus rather ovate, paraclypeus narrowed rectangular. Tentorial fovea traversed mesially gena and eye. Labrum rather circular and posterior of frontoclypeus, bearing two postero-lateral projections, pilifers. Labial palpi posterior of labrum, between maxillae, longer than one third of the length of maxillae. Maxillae extending to A3. Mandibles small, posterior of gena and eye. Maxillae palpi, triangular sclerite, posterior of eyes, anterior of pro- and mesothoracic legs.

  Thorax: Segments visible in dorsal view. Prothorax trapezoidal, concave mesially anaterior and posterior margins; prothoracic legs positioned between maxilla and mesothoracic legs. Mesothorax large, metathorax emarginated medially; mesothoracic legs between lateral margins of prothoracic legs and antennae, ending after labial palpi; metathoracic legs extending to A5, only visible apically. Forewing covering most parts of lateral and ventral thorax, ending before posterior margin of A5. Hindwings completely covered by forewing.

  Abdomen: ten segments visible in dorsal view; spiracles visible laterally in segments A2–A7. Remnants of larval prolegs visible in ventral margin of A6. Genital and anal opening visible in ventral margin of A8 and A10 respectively.

- **Adult** (Figure 5a,b); Wingspan 16.0–21.0 mm. Vertex rough and erected brown gray or scales with two black dots-like scales anteriorly, frons brown gray appressed scales, cream white scales around compound eye. Antenna brown gray. Labial palpus porrect, 1st segment brown gray and white scales mixed together, 2nd and 3rd segments brown

gray. Foreleg femur to tibia brown gray, tarsus brown gray, irrorated brown; mid- and hindleg pale yellow white, irrorated brown gray dorsally. Thorax brown gray, one pair of black dots 2/5 anteriorly, another one pair of dots 2/3 at anteriorly and one dot at base, tegula brown gray with a black dot near base. Abdomen pale brown gray. Forewing brown gray with black line from base to 2/5 in costal margin, about 71–82 black dots on forewing, viz., 8 subcostal from near base to near 1/2, 11–12 radial near base to near costa at 5/6, 3–4 subradial middle to 4/5, 4–5 dots between subradial and supramedian, pale black irregular patch between supramedian and submedian 4/5 base, 8–11 supramedian from 1/3 basal to near termen, 2–3 dots between supramedian and submedian, 12–14 dots series from near base to near apical of chorda, 12 submedian from base to tornus, pale black irregular patch irrorated between submedian and subdorsal at 2/5 base, 11–13 subdorsal near base to before tornus, fringe gray. Hindwing and fringe gray.
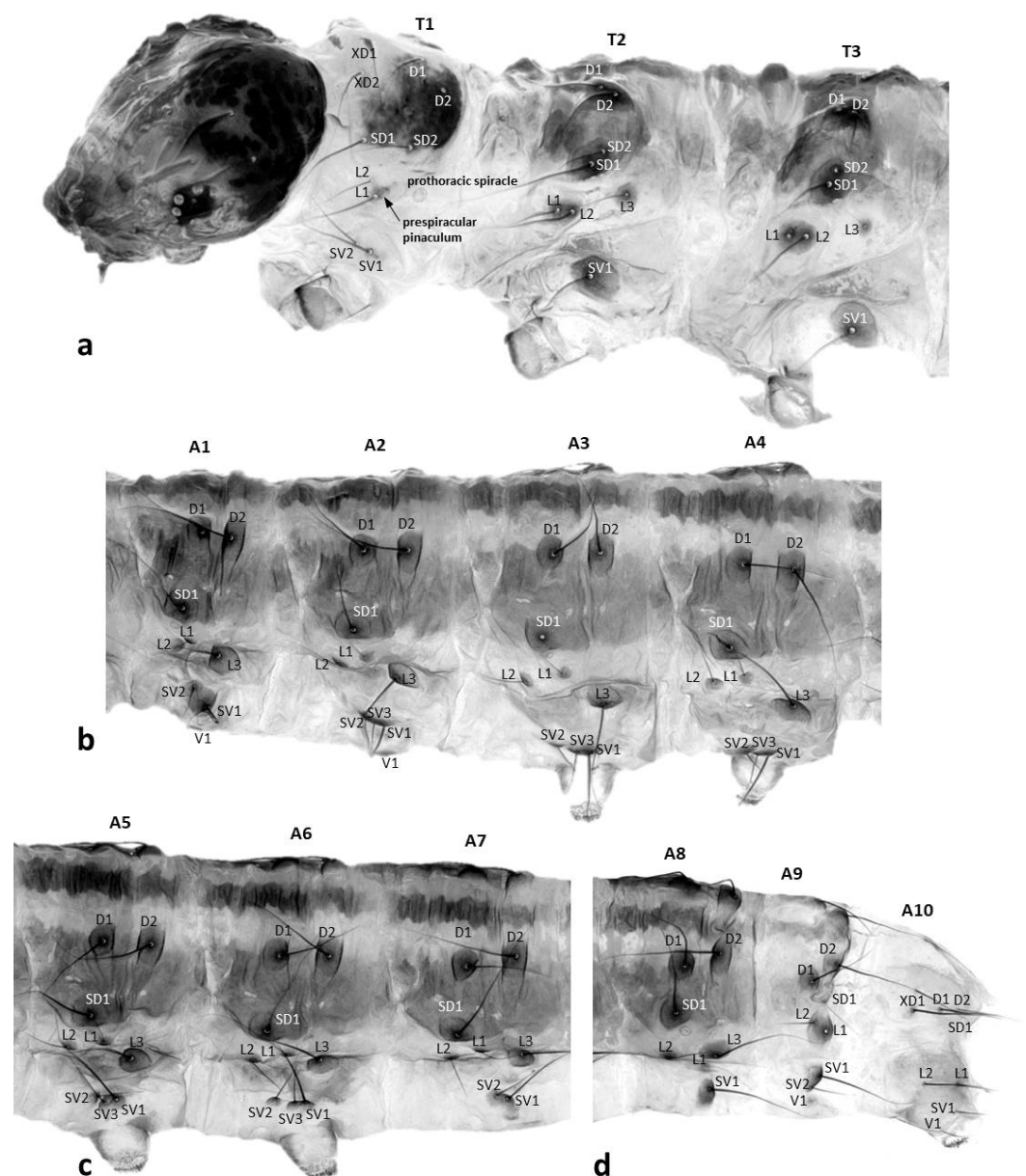
Figure 3. Chaetotaxy in larva of *Yponomeuta meguronis*: (**a**) T1–T3; (**b**) A1–A4; (**c**) A5–A7; (**d**) A8–A10. Abbreviation: D, dorsal setae; L, lateral setae; SD, subdorsal setae; SV, subventral setae; T1, prothorax, T2, mesothorax, T3, metathorax, A, abdominal segment.
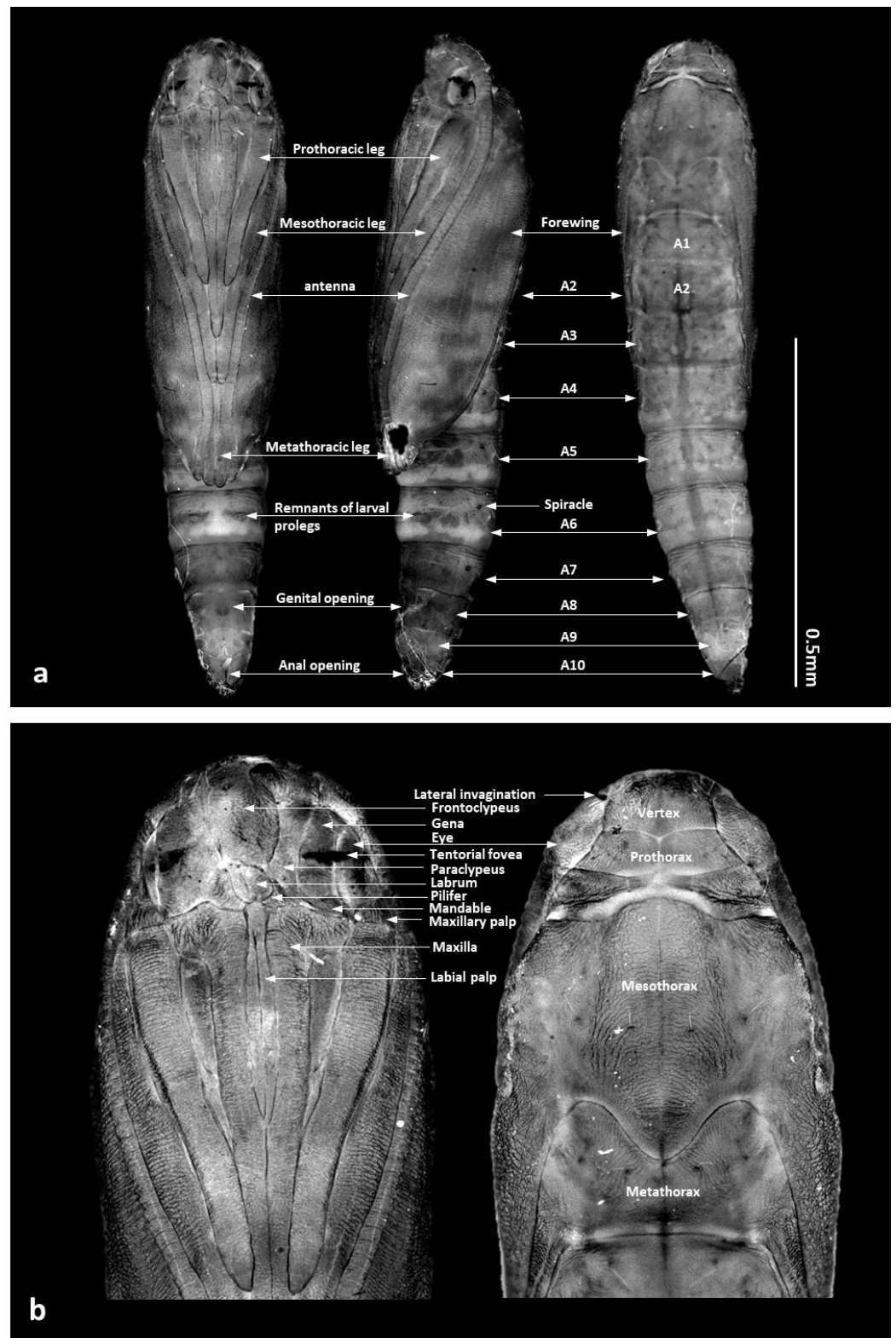
Figure 4. Pupa of *Yponomeuta meguronis*: (**a**) ventral, lateral, and dorsal views; (**b**) caput.
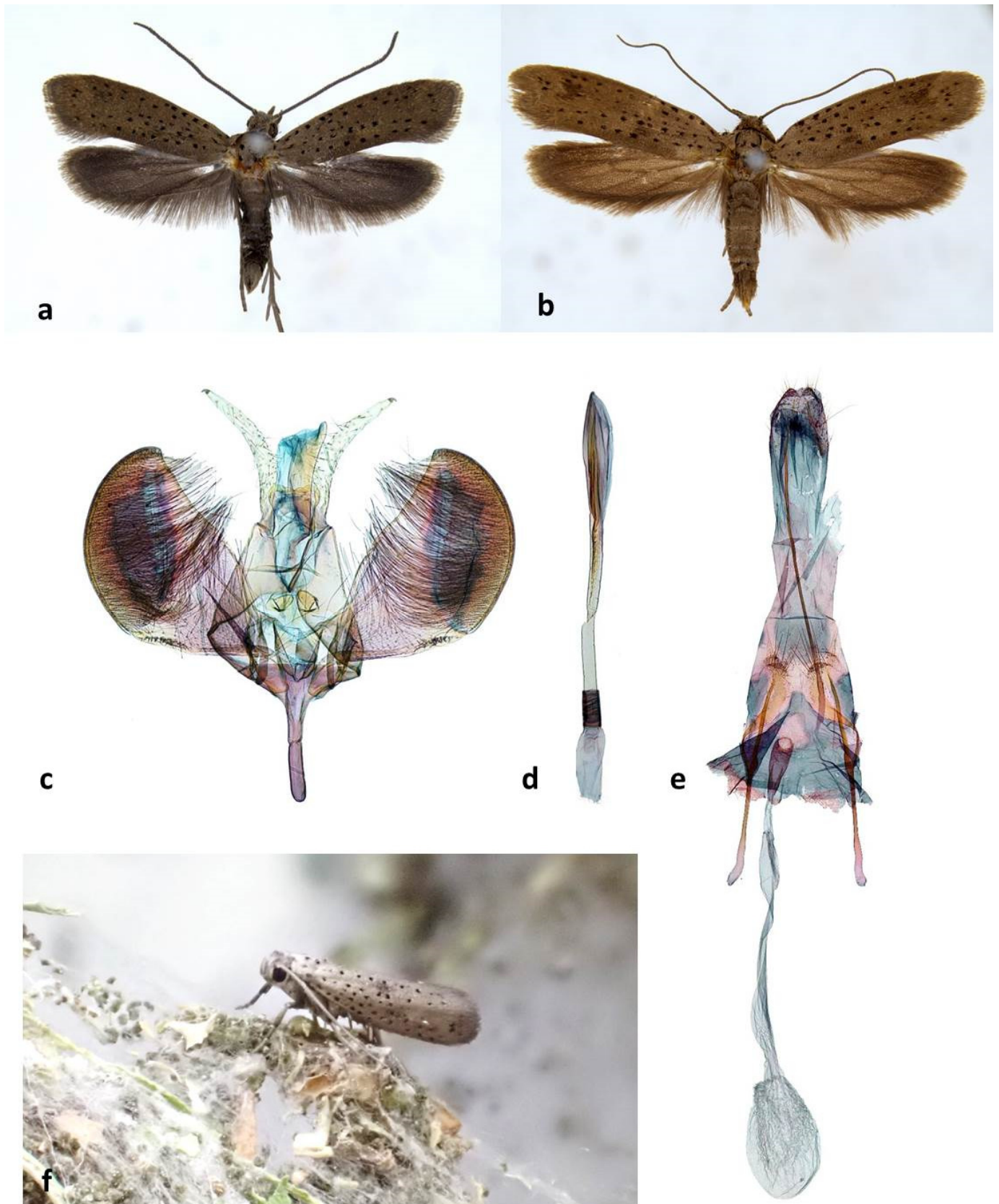
Figure 5. Adult of *Yponomeuta meguronis*: (**a**,**b**) dorsal view of adults; (**c**) male genitalia; (**d**) aedeagus; (**e**) female genitalia; and (**f**) newly emerged adult.

Male genitalia (Figure 5c,d). Uncus well-dilatated at each corner, concave at middle. Socius curved outwardly, some hair-like setae sparsely with two thorn at apex. Tuba analis membranous. Gnathos a pair of tongue-shaped processes without spinules. Valva triangular, curved outer margin, little curved apex inwardly at dorsal margin; sacculus defined from base to 1/3 dorsal margin, narrowed with some bristles in distal 1/4. Saccus slender, little-dilatated apex, about 1/3 length of aedeagus. Aedeagus about 1.5 times as long as valva, with cornuti composed of two spines posteriorly and two spines with many spinules anteriorly. Coremata well-developed.

Female genitalia (Figure 5e). Papillae anales semioval with hair-like setae. Intersegmental membrane between papillae anales and 8th segment about 1.5 times as long as 8th segment. Apophyses anteriores branched and 1.5 times as long as apophyses posteriores. Lamella postvaginalis produced a pair of semioval pads with erected setae. Ostium bursae ringed, spinulated; antrum parallel-sided, sclerotized, about 1/4 as long as ductus bursae. Ductus bursae over two times as long as corpus bursae, membranous, with ductus seminalis at 1/7 posteriorly. Corpus bursae oval, without signum.

3.1.3. Material Examined

72 males and 71 females, Chungcheongnam-do, Taean-gun, Sowon-myeon, Uigyang-ri, 977-18, 12–18 May 2021, S. Kim; 1 female, Incheon-si, Is. Yongyu, 17 September 1997, M.K. Paek & N.H. Ahn; 5 males, 3 females, Gyeongsangbuk-do, Uleung-gun, Is. Dok(do), 23 June 2007, Bae et al.; 1 female, Gyeongsangbuk-do, Uljin-gun, Geunnam-myeon, Gusan-ri, (36°55′52.34″ N, 129°21′32.05″ E), 15 November 2014, Y.D. Ju, S.M. Na & J.W. Kim.

3.1.4. Biology

Eggs hatch at the end of April. Larvae are gregarious by making a silk web, and feed on leaves. Within the silk web, cocoons hang vertically. More than 150 larvae (1–2 instars) were collected from a colony of *Euonymus japonicus* on 3 May 2021; then, adults emerged from the pupal case from 12 to 18 May of 2021 (Figure 5f).Its adults were collected in May, June, September, and November. Thus, they were expected to have offspring more than twice a year.

Most *Yponomeuta* larvae can survive the winter season at temperatures down to –40 °C [26]. First, instar larvae hibernate under "shield", where females lay eggs or secrete mucus. They are a similar color to bark and are round or elongated oval in shape. The larvae make a web nest, entwining twigs and leaves with a silken thread. However, the larvae do not molt simultaneously; sometimes, larvae exhibit different instars in one nest. Adult *Yponomeuta* have a resting position which is parallel to the substrate, wings folded, and antennae nearly pressed to the wings [27].

3.1.5. Host Plant

Euonymus fortunei (Turcz.) Hand.–Maz., *Euonymus japonicus* Thunb. ([11]; this study).

3.1.6. Distribution

Palaearctic: Korea (Taean-gun, Is. Yongyu(do), Is. Dok(do), Gusan-ri; this study), Japan (Honshu, Kyushu, Shikoku).

3.1.7. Natural Enemies of *Y. meguronis*

During the breeding of *Y. meguronis*, we discovered one parasite and one predator, as follows:

- *Herpestomus brunnicornis* (**Gravenhorst, 1829**) (**Hymenoptera: Ichneumonidae**) (Figure 6)
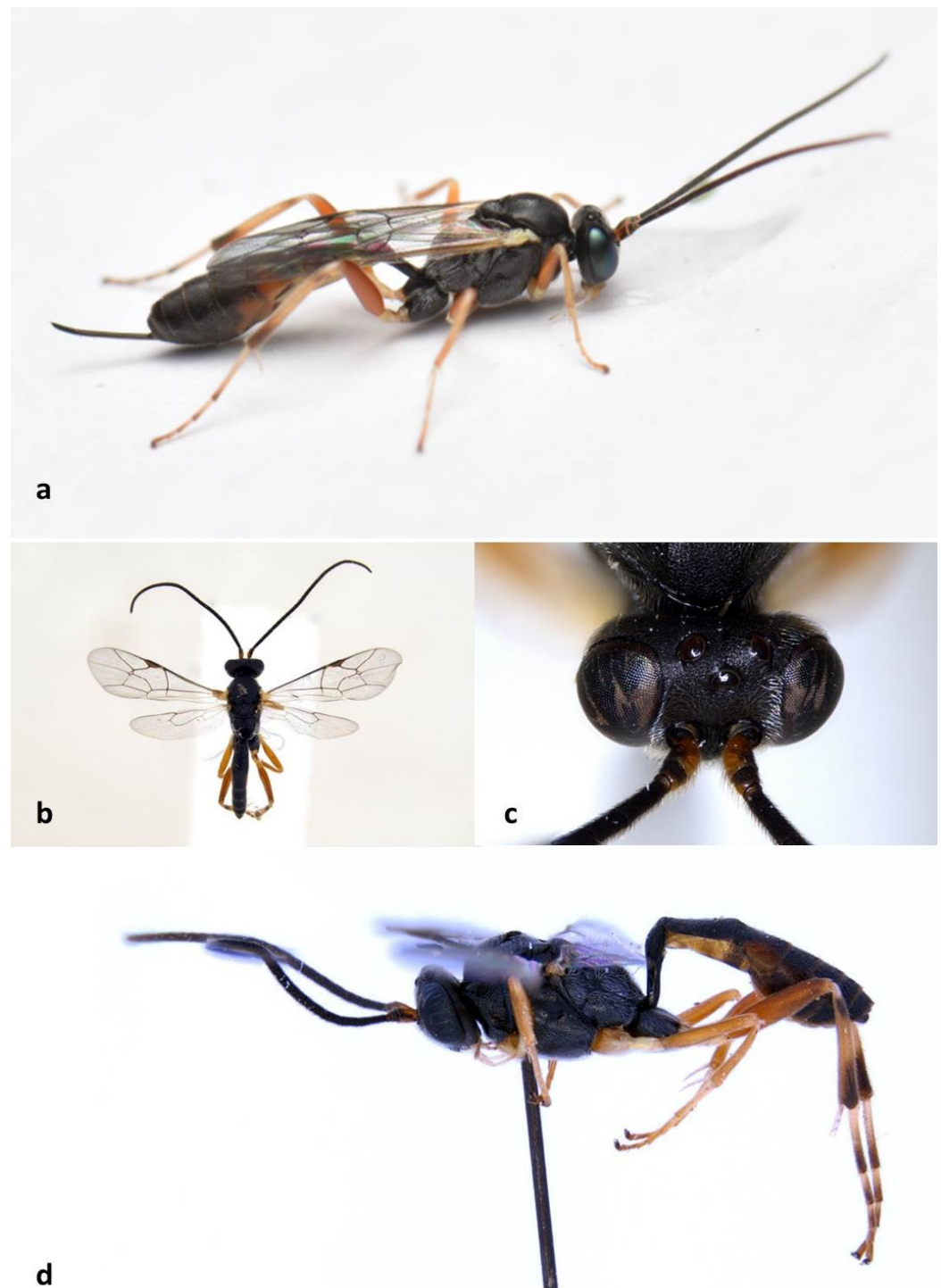
Figure 6. *Herpestomus brunnicornis,* a natural enemy of *Yponomeuta meguronis*: (**a**) ecological photo; (**b**) dorsal view; (**c**) head; and (**d**) lateral view.

This species was newly recognized as the most numerous parasitoid of *Y. meguronis* in this study. According to the literature, this species is also known to be a natural enemy of other *Yponomeuta* species: *Y. cagnagella* (spindle ermine moth), *Y. evonymella* (bird-cherry ermine moth), and *Y. padella* in Europe and *Y. malinelllus* (apple ermine moth) in Korea, Japan and China [14].

- *Xanthandrus comtus* (**Harris, 1780**) (**Diptera: Syrphidae**) (Figure 7)
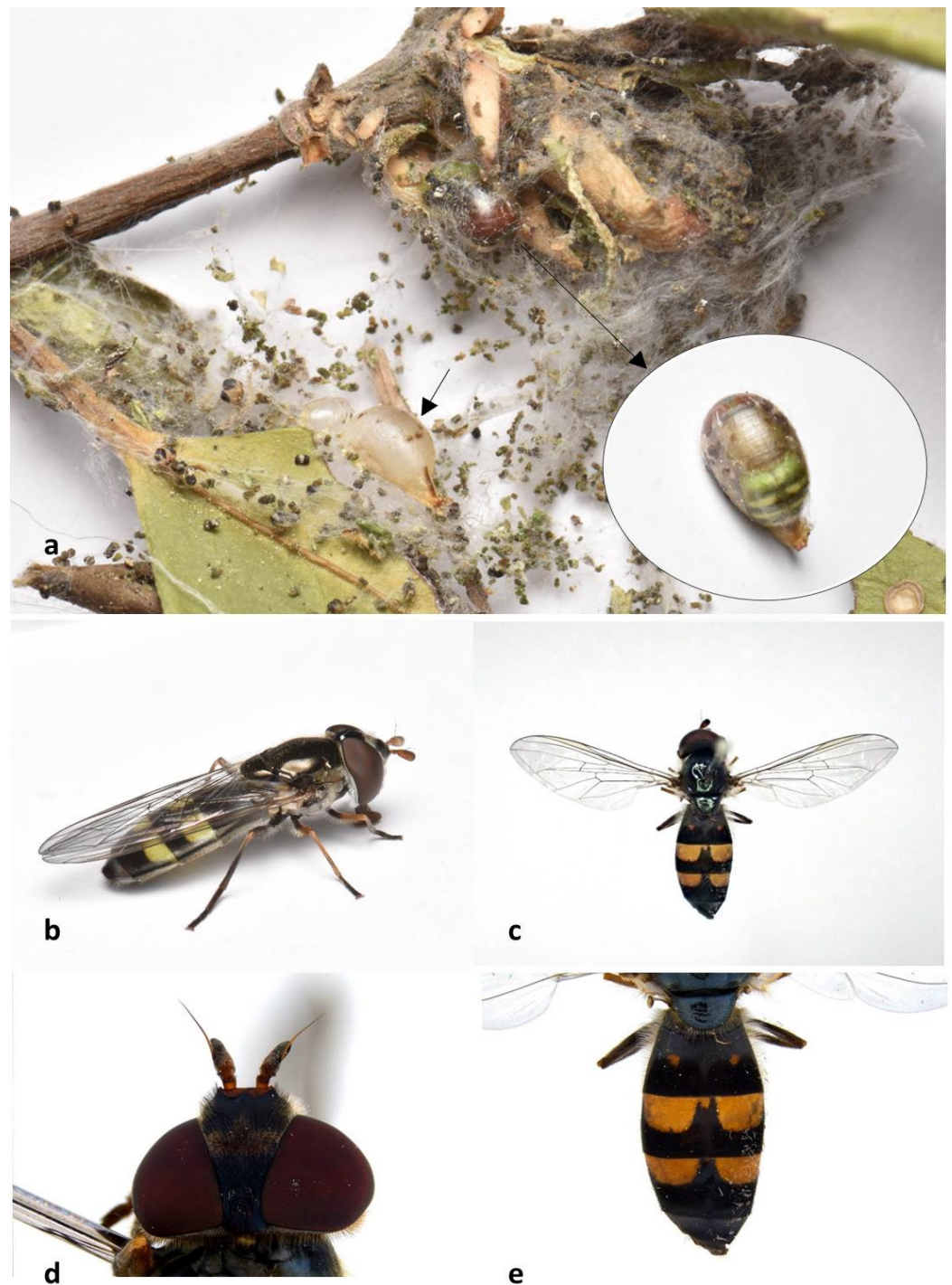
Figure 7. *Xanthandrus comtus*, a natural enemy of *Yponomeuta meguronis*: (**a**) pupa and exuvium; (**b**) ecological photo; (**c**) dorsal view; (**d**) head; and (**e**) abdomen.

This species was firstly confirmed as a natural enemy of *Yponomeuta* species from this study. According to previous researchers [28–30], *Xanthandrus* is a predator of various hyponemutid and tortricid larvae. Additionally, Rotheray and Gilbert [31], in their personal communication with F.C. Thompson, presented that non-European species all seem to be specialized Lepidopteran predators.

From this study, for the first time, this species has been revealed as a predator of *Y. meguronis.* They fed on larvae of *Y. meguronis* during the larva stage, and then pupated in the same host plant.

4. Conclusions

- Our results provide new descriptions of the larva and pupa of *Y. meguronis* as a forestry insect pest.
- We discovered that *Y. meguronis* causes serious damage to *Euonymus japonicus* Thunb. in Korea.
- We have newly reported two natural enemies of *Y. meguronis*, *Herpestomus brunnicornis* of Ichneumoninae, as a parasitoid and *Xanthandrus comtus* of Syrphidae, as a predator.
- The necessity of establishing an insect pest morphological and ecological database that can accurately identify pests and control and manage serious pests will continue to increase in the future.

5. Discussion

Through this study, we found that *Y. meguronis* is a forestry insect pest that causes serious harm to *Euonymus japonicus*. In Korea, there are many *Euonymus japonicus* colonies. Is. Dok(do) is particularly famous for this. The descriptions of larvae, a period of actual damage, and pupa, another immature stage, were first presented with biological data, such as the possibility of two generations per year, and natural enemies. However, no biological data on egg, female fertility, and general lifespan were obtained.

In fact, *Yponomeuta*, which is a higher level of *Y. meguronis*, has mainly been studied by European researchers of severe pests and as an invasive species to the United States. Starting with this study, close research on Asian *Yponomeuta* will be required, and we think that a precise plan will be needed to obtain more complementary results.

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Conflicts of Interest: The authors declare no conflict of interest.

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