COMPARATIVE MORPHOLOGICAL STUDIES ON TWO SPECIES OF *ALEYRODES* (HEMIPTERA: ALEYRODIDAE)

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Reprinted from THE PAN-PACIFIC ENTOMOLOGIST
Vol. 83, No. 3, September 2007
Made in United States of America

THE PAN-PACIFIC ENTOMOLOGIST
83(3):244–254, (2007)

Comparative morphological studies on two species of *Aleyrodes* (Hemiptera: Aleyrodidae)

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Abstract. The whitefly species, *Aleyrodes shizuokensis* Kuwana 1911 is re-recorded from Taiwan for the first time since Takahashi (1935). The puparia and adults of two morphologically similar species, *A. proletella* (Linnaeus 1758) and *A. shizuokensis* Kuwana 1911, are redescribed and illustrated. A detailed morphological comparison between the species is made.

Key Words. Hemiptera, Aleyrodidae, *Aleyrodes*, adults, Taiwan.

INTRODUCTION

The whitefly species *Aleyrodes proletella* Linnaeus 1758 and *A. shizuokensis* Kuwana 1911 (Hemiptera: Aleyrodidae) are morphologically very similar. *Aleyrodes proletella* was first described in Lepidoptera, subsequently placed in Hemiptera: Coccidae and was later moved to the family Aleyrodidae. The species is quite widespread in many countries including Taiwan. Mound & Halsey (1978) listed 12 host plant families for this whitefly; however, it prefers cruciferaceous over asteraceaeous hosts.

Aleyrodes shizuokensis was described on *Oxalis corniculata* Linnaeus (Oxalidaceae). So far it has been recorded from Japan, Hawaii, India, and Taiwan (Kuwana 1911, Singh 1931, Takahashi 1951). Takahashi (1935) was the first to collect it from Taiwan (Kaohsiung), on *Sonchus oleraceus* Linnaeus (Asteraceae). It was thought that this species might have been eradicated from Taiwan, or that Takahashi's (1935) record was a misidentification, until we collected it again recently. Here *A. shizuokensis* is re-recorded from Taiwan, and accurate descriptions of the puparium and adults are provided.

Many articles on *A. proletella* have been published during the past two centuries, but no morphological comparison has been made between *A. proletella and A. shizuokensis*. In this work, the morphology of these species is compared, figures are provided.

The material examined in this study has been deposited in the collection of the Department of Entomology, National Taiwan University, Taipei, Taiwan.

METHODS AND MATERIALS

Leaf undersides bearing eggs and late instar nymphs of the above species were collected in Taiwan, and a colony of each species was established in the laboratory. Emergent parasitoids were removed. Descriptions and terminology of the external and interior morphological structures are based on those of Bink-Moenen (1983),

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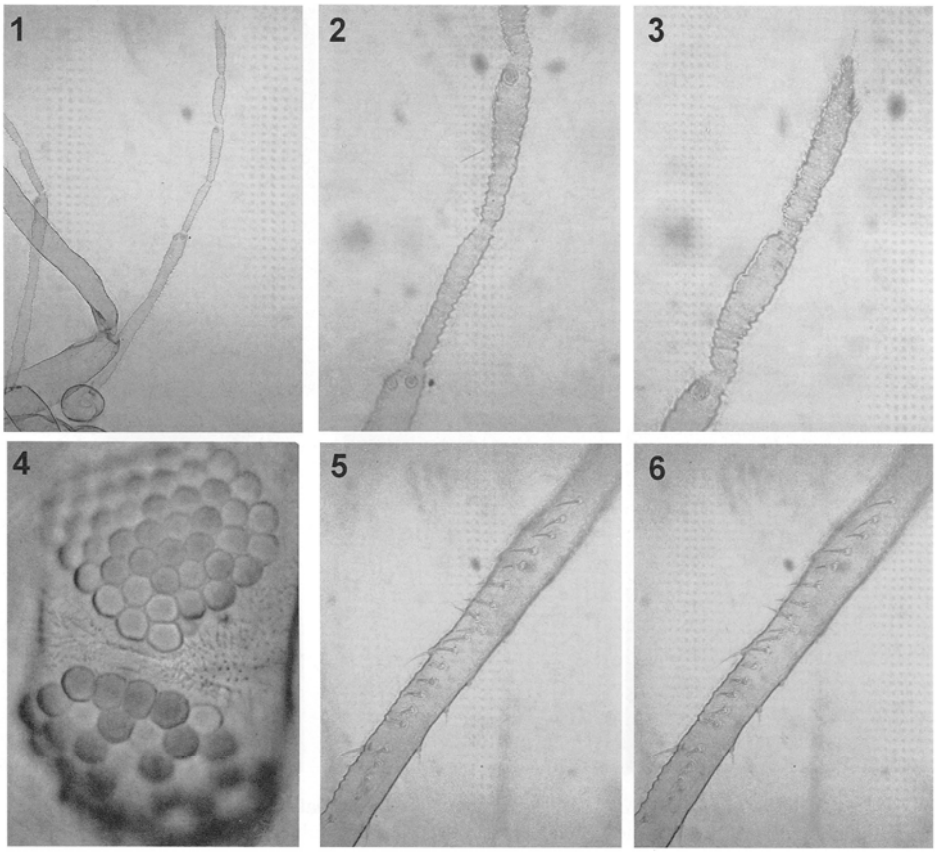


Figures 1–6. *Aleyrodes proletella* (Linnaeus). 1, Antenna; 2, Antennal segments IV–V; 3, Antennal segments VI–VII; 4, Compound eyes of adult male; 5, Mesotibial brushes of adult male; 6, Metatibial comb and brush of adult male.

Martin (1985), Gill (1990) and Guimarães (1996). Measurements are based on five individuals of each species.

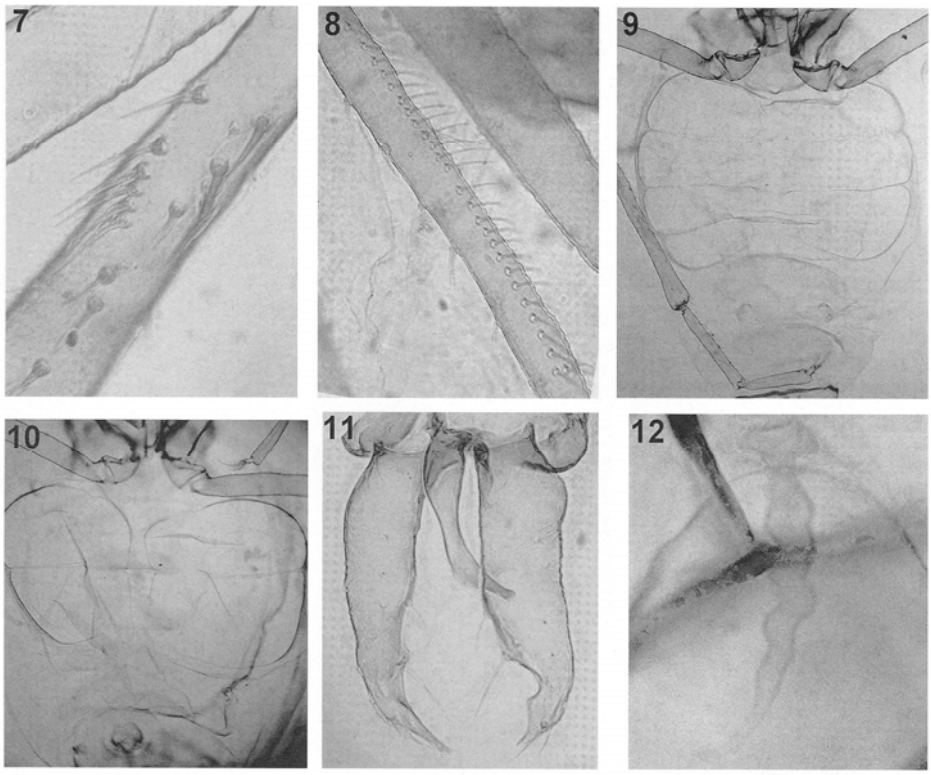
Descriptions of the two morphologically similar species are as follows:

Aleyrodes proletella (Linnaeus 1758)
(Figs. 1–12, 25, 27)

Phalaena (*Tinea*) *proletella* Linnaeus 1758:537–538. [in Lepidoptera] Syntype data: "Habitat in *Brassica*, *Chelidonio*; an etiam in *Quercu*?".

Aleyrodes proletella (Linnaeus) Latreille 1801–2:264, Bink-Moenen 1983:86–87, Martin 1987:307, Kozar & Bink-Moenen 1988:119, Mifsud 1995:69, Ko et al. 1998, Martin 1999:54.

Diagnosis. Puparium (Fig. 25): pale to white, average size 0.97 mm long, 0.74 mm wide; elongate to ovoid, broadest at metathorax. Found in groups on the undersurface of leaves. Margin crenulate. Pairs of marginal setae present in anterior and posterior areas. Caudal and thoracic tracheal areas not evident. Groups of immatures dusted with white powdery wax. Dorsum. Cephalic, first and VIII



Figures 7–12. *Aleyrodes proletella* (Linnaeus). 7, Mesotibial brushes of adult female; 8, Metatibial comb and brush of adult female; 9, Wax plates of adult male; 10, Wax plates of adult female; 11, Aedeagus and claspers; 12, Cement gland.

abdominal setae present. Longitudinal molting suture reaching margin and transverse molting suture reaching subdorsum. Abdominal segment sutures ending on subdorsum. Submarginal caudal setae each about 17.7 μm long; abdominal segments I–VIII visible, abdominal segment VII not reduced medially. Vasiform orifice cordate, posterior margin truncate, with lateral teeth on both sides; a little shorter than wide, 57.1 × 59.0 μm. Operculum rounded-trapezoidal, 1.65 times as wide as long (47.6 × 28.9 μm); truncate at hind margin, occupying about 1/2 of the orifice. Lingula exposed, included, 48.9 μm long, apex slightly tapering, spinulose; a pair of subapical setae present, each about 27.6 μm long. Caudal furrow and ridges absent. Venter. A pair of ventral abdominal setae present. Antenna not extending beyond base of prothoracic leg. Outline of legs curved. Tiny setae present at bases of legs and rostrum.

Adult ♂: length from vertex to claspers, 1.13 mm. One ocellus present laterally on each side, located close to upper compound eye. Upper and lower compound eyes not joined, as in *Trialeurodes vaporariorum* (Westwood 1856); with a tiny tubercle, close to upper compound eye (Fig. 4). Tip of labium with sensorial hairs. Antenna. As in other *Aleyrodes* spp., 7-segmented, with 4 primary sensoria and 3 sensorial cones (Fig. 1). Segment III longest, bearing 2 primary sensoria sub-apically and 1 sensorial cone, tip of cone extending to base of sub-apical primary sensorium;

segment V with a primary sensorium apically (Fig. 2); segment VI with a sensorial cone situated subapically, distal end extending to junction of segments V and VII; segment VII with a primary sensorium, sensorial cone situated in distal 1/2 and a seta present at tip, cone 1/3 of segment VII (Fig. 3). Wings: forewing 0.96 mm long, 0.44 mm wide. Hindwing 0.82 mm long, 0.31 mm wide. Wings mottled in middle and at end of radial vein, limpid, covered with white waxy secretions. Wing venation reduced to costal-subcostal veins and radial vein. Legs: mesotibia with ordinary rows of spines, each brush with 3 setae on each side (Fig. 5). Metatibial comb usually with rows of 20 spines, numbers of spines varying (19–22) with specimen, brush with 3 setae (Fig. 6). Vasiform orifice: operculum subtrapezoidal. Lingula subcylindrical, exposed and spinulose, excluded, a pair of short setae present at tip (Fig. 27). Genitalia: aedeagus 68.6 μm long, 13.1 μm wide at base, much shorter than clasper, curved in middle. Clasper 111.3 μm long, 31.7 μm wide at base, a pair of semicircular concavities present sub-apically, a pair of long setae present on inner margin, subapical tooth visible (Fig. 11).

Adult ♀: most characters similar to those of the male. Vertex to tip of ovipositor 1.25 mm long. Forewing 1.19 mm long, 0.57 mm wide. Hindwing 1.00 mm long, 0.42 mm wide. Mesotibia with rows of spines, brushes with 3 and 4 setae (Fig. 7). Metatibial comb usually with rows of about 25 spines in most individuals (number varies from 20 to 29), brush with 3 setae (Fig. 8). Genitalia: 7 pairs of setae present on each gonapophysis - 3 pairs situated centrally and 4 pairs laterally. Bulb-like orifice of cement gland trapezoidal, extremely curved, not mottled, 48.6 μm long (Fig. 12).

Specimens examined. TAIWAN: TAOYUAN HSIEN: Fuhsing, 13 puparia, 18 August 2005, C. H. Chen; HSINCHU HSIEN: Chulin, 3 puparia, 17 February 2006, C.H. Hsien; HUAYUAN, 6 puparia, 10 May 2006, C.H. Chen; TAICHUNG HSIEN: Shihkung, 4 puparia, 19 May 2006, Y.T. Shih; CHANGHUA HSIEN: Chihu, 11 puparia, 20 February 2006, Y.T. Shih; NANTOU HSIEN: Wushe, 22 puparia, 9 third instars, 1 second instar, 19 January 2006, C.H. Chen; PULI, 1 puparium, 24 October 2004, Y.F. Chen; TSAOTUN, 8 puparia, 13 April 2003, C.C. Liu; CHUSHAN, 47 puparia, 18 April 2006, C.C. Ko; CHIAYI HSIEN: Chunpo, 8 puparia, 5 April 2005, C.C. Ko; ICHU, 30 adult females, 5 adult males, 6 January 2002 , C.C. Ko; 5 adult females, 1 adult male, 3 February 2002, C. C. Ko; 5 adult females, 16 March 2002, C.C. Ko; 28 puparia, 14 May 2006, C.C. Ko; TAINAN HSIEN: Paiho, 4 adult females, 3 adult males, 24 April 2004, C.C. Ko; KAOHSIUNG HSIEN: Tashu, 40 puparia, 3 April 2005, C. H. Hsien; ILAN HSIEN: Wuchieh, 6 puparia, 1 adult female on *Lactuca formosana* Maximowicz (Asteraceae), 19 April 2006, C.H. Chen; HUALIEN HSIEN: Yuli, 1 puparium, 18 March 2006, C.H. Hsien; TAITUNG HSIEN: Tulan, 3 puparia, 26 April 2006, C.H. Chen; CHANGPIN, 9 puparia, 7 adult females, 2 adult males, 4 May 2004, H.T. Yeh; PEIMAN, 3 puparia, 18 March 2006, C.H. Hsien; LUTAO (Green Island), 3 puparia, 27 June 2004, C.H. Hsien; (all collected from *Lactuca indica* Linnaeus (Asteraceae), and deposited in NTU collection except when specified elsewhere); LIANCHANG HSIEN: NANKANG, 4 puparia, on *Crepidiastrum lanceolatum* (Houttuyn) Nakai (Asteraceae), 6 September 2003, C.H. Hsien; 4 puparia, 1 adult female, 1 adult male on *Sonchus oleraceus*, 13 April 2003, C.H. Hsien.

Host plants (based on Mound & Halsey 1978). Apiaceae: *Laser trilobus* (Linnaeus); Asteraceae: *Acanthocephalus benthamianus* (Regel) Keine, *Cephalorrhynchus* sp., *Cichorium* sp., *Crepidiastrum lanceolatum* (Houttuyn), *Emilia sonchifolia* (Linnaeus),

Inula sp., *Lactuca formosana* Maximowicz, *Lactuca indica* Linnaeus, *L. muralis* (Linnaeus), *Pterocypsela triangulata* (Maximowicz), *Lapsana communis* Linnaeus, *Mutisia acutifolium* Blake, *Prenanthes purpurea* Linnaeus, *Sonchus arvensis* Linnaeus, *S. oleraceus* Linnaeus, *Sonchus* sp., *Steptorhamphus crambifolius* Bunge, *Taraxacum officinale* Weber ex Wiggers; Balsaminaceae: *Impatiens parviflora* DC; Berberidaceae: *Bongardia chrysogonum* (Linnaeus); Campanulaceae: *Codonopsis clematidea* (Clarke), *Ostrowskia magnifica* Regel; Cruciferae: *Brassica balearica* Persoon Chase, *B. cretica* Lamarck, *B. incana* (Linnaeus), *B. macrocarpa* Gussone, *B. oleracea* Linnaeus, *B. robertiana* (Rouy & Foucaud), *B. tinei* Lojacono, *Chriranthus* sp., *Lepidium latiolum*, *Rorippa indica* (Linnaeus); Euphorbiaceae: *Euphorbia peplus* Linnaeus; Fabaceae: *Vicia faba* Linnaeus; Fagaceae: *Quercus robur* Linnaeus; Oxlidaceae: *Oxalis* sp.; Papaveraceae: *Chelidonium majus* Linnaeus; Ranunculaceae: *Aquilegia montana* Sternberg, *A. laciolum*, *Thalictrum minus* Linnaeus; Scrophulariaceae: *Linaria* sp.

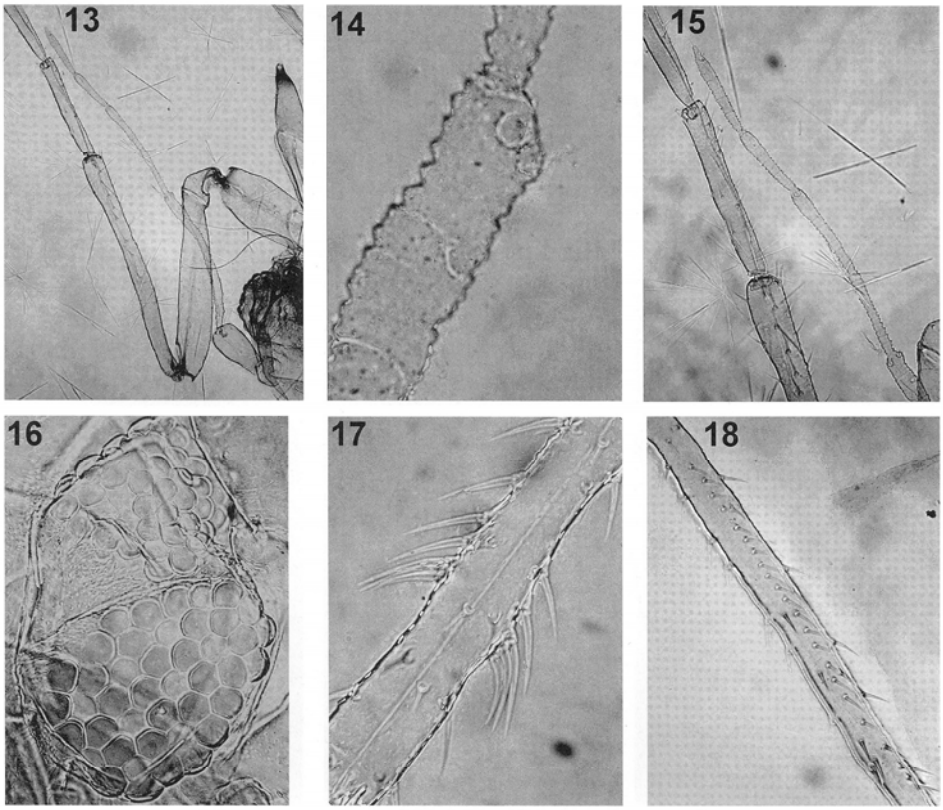
Distribution (based on Mound & Halsey 1978 and Martin 1999). Palaearctic region: Austria, Italy, Bermuda, Canary Islands, Czechoslovakia, Egypt, England, Eurasia, Finland, France, Germany, Hungary, Macaronesian islands, Morocco, Poland, Russia, Spain, Sweden, Switzerland, Yugoslavia; Ethiopian Region: Angola, Cape Verde Islands, Kenya, Mozambique, South Africa; Neotropical region: Brazil; Oriental region: Taiwan (Changpin, Chihu, Chulin, Chunpo, Chushan, Fangshan, Fuhsing, Huayuan, Ichu, Kungkuan, Lutao [Green Island], Minchi, Mucha, Nankang, Paiho, Peiman, Puli, Santimen, Shanpin, Shihkung, Tashu, Tsaotun, Tulan, Wuchieh, Wufeng, Wulai, Wushe, Yuli); Pacific region: Australia, New Zealand; Nearctic region: eastern U.S.A.

Biology. In Taiwan, this species is apparently restricted to members of the Asteraceae, especially *Lactuca indica*, and currently is of no economic importance. Elsewhere, it almost exclusively feeds on members of the Cruciferae and, being a minor pest of brassica crops in Europe, is commonly called the European cabbage whitefly. The eggs are laid upright in a semicircle on the underside of leaves. In Taiwan, egg-laying took place from mid-May to September. The entire life-cycle took 1 month on cabbage, and there were usually 4 or 5 generations in a year. The puparia were found in groups, often heavily infesting the undersurfaces of leaves amid a white wax secretion. *A. proletella* was sometimes found together with *Bemisia tabaci* (Gennadius 1889) or *Trialeurodes vaporariorum* (Westwood 1856). Based on collection localities in Taiwan and distributions of the host plants, this species might have a wider distribution than the present records indicate. No ant attendance was observed.

Aleyrodes shizuokensis Kuwana 1911
(Figs. 13–24, 26, 28)

Aleyrodes shizuokensis Kuwana 1911:620–622. Syntypes on *Oxalis corniculata*, Japan: Shizuoka, 1908 (Masuda) (TARI) (USNM).

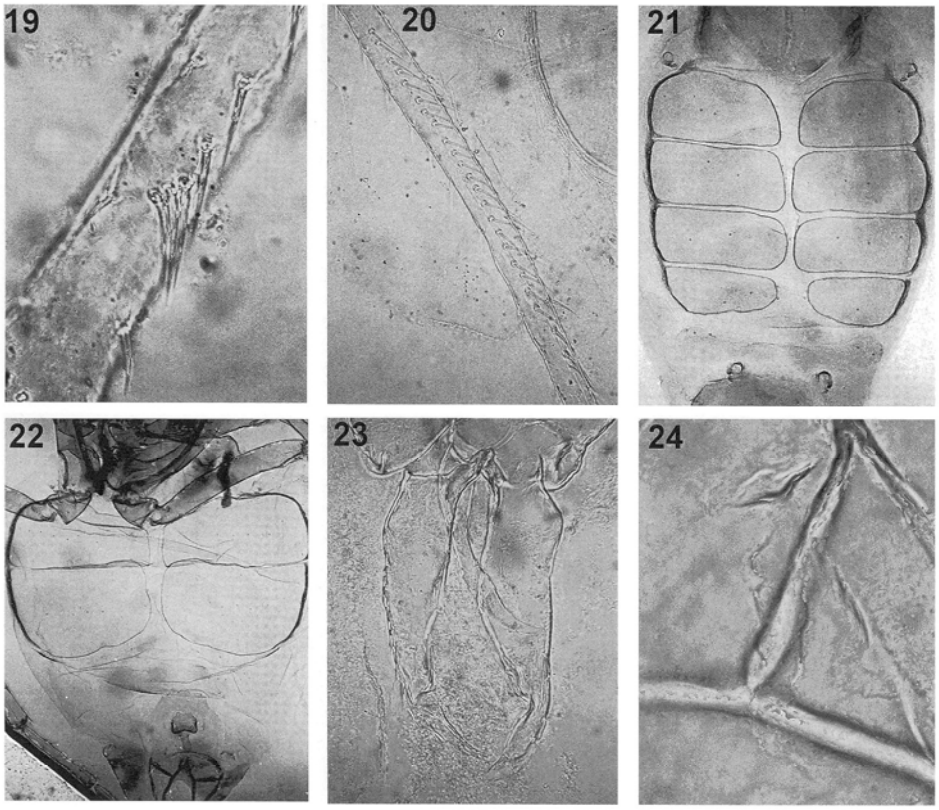
Diagnosis. Puparium (Fig. 26): pale to white, average size 0.92 mm long, 0.69 mm wide; elongate to ovoid, broadest at metathorax. Found in groups on the undersurface of leaves. Margin crenulate. Pairs of marginal setae evident in anterior, posterior, caudal and thoracic tracheal areas. Groups of immatures dusted with white powdery wax. Dorsum: with 4 pairs of long setae: cephalic, mesothoracic, I–VIII abdominal setae present, measuring 98.0, 72.2, 56.3, and 89.4 μm respectively. Submarginal caudal setae each about 39.2 μm long. Longitudinal molting suture



Figures 13–18. *Aleyrodes shizuokensis* Kuwana. 13, Antenna; 14, Antennal segments IV–V; 15, Antenna segments VI–VII; 16, Compound eyes of adult male; 17, Mesotibial brushes of adult male; 18, Metatibial comb and brush of adult male.

reaching margin and transverse molting suture reaching subdorsum. Abdominal segment sutures ending on subdorsum. Abdominal segment VII not reduced medially. Vasiform orifice cordate, posterior margin truncate, with lateral teeth on inner wall; a little longer than wide, 42.0 × 45.7 μm. Operculum rounded-trapezoidal, 37.0 × 19.6 μm; truncate at hind end, occupying about 1/2 of orifice. Lingula 34.2 μm long, apex slightly tapering, spinulose and exposed; bearing a pair of subapical setae, each about 17.1 μm long. Caudal furrow and ridges absent. Venter. Antenna not extending beyond base of prothoracic leg. Outline of legs curved. Tiny setae present at bases of legs and rostrum.

Adult ♂ similar to *A. proletella* except: mottled on head, and meso- and metathoracic pleurons. Length from vertex to claspers, 1.22 mm. With 2 tiny tubercles at interval of compound eyes, closer to upper compound eyes (Fig. 16). Forewing 0.92 mm long, 0.40 mm wide. Hindwing 0.77 mm long, 0.27 mm wide. Wings only mottled at end of radial vein. Mesotibia with ordinary rows of spines, brushes with 3 and 4 setae (Fig. 17). Metatibial comb usually with rows of 19 spines (in most individuals), numbers of spines varying (17–19) (Fig. 18). Vasiform orifice: operculum rounded-trapezoidal. Lingula short, subcylindrical, exposed and hairy, a pair of short setae present at tip of lingula (Fig. 28). Genitalia: aedeagus 89.8 μm



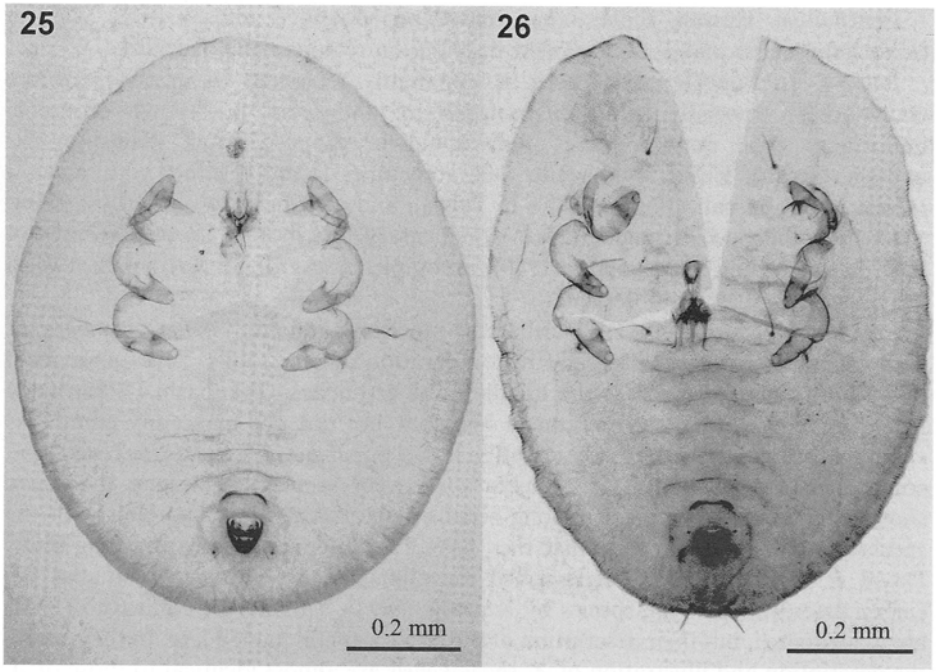
Figures 19–24. *Aleyrodes shizuokensis* Kuwana. 19, Mesotibial brushes of adult female; 20, Metatibial comb and brush of adult female; 21, Wax plates of adult male; 22, Wax plates of adult female; 23, Aedeagus and claspers; 24, Cement gland.

long, 13.9 μm wide at base. Claspers each about 29.4 μm at base, 112.7 μm long (Fig. 23).

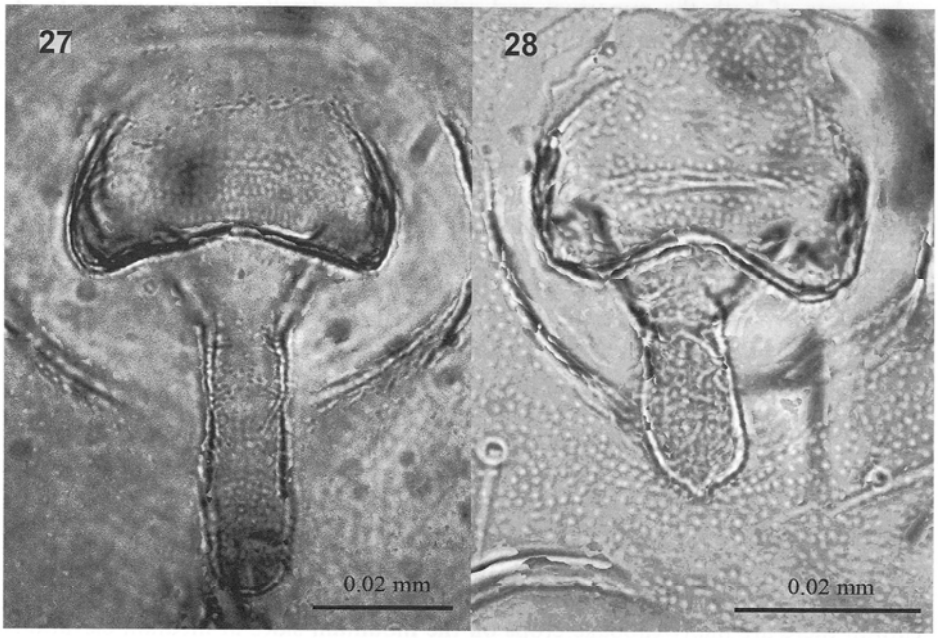
Adult ♀ similar to male except: vertex to tip of ovipositor 1.21 mm long. Forewing 0.96 mm long, 0.42 mm wide. Hindwing 0.82 μm long, 0.34 μm wide. Mesotibia with rows of spines, brushes with 3–4 setae (Fig. 19). Metatibial comb usually with rows of 20 spines (in most individuals), numbers of spines varies from 20–22 (Fig. 20). Genitalia: 7 pairs of setae present on each gonapophysis, distributed as in *A. proletella*. Bulb-like orifice of cement gland trapezoidal, extremely curved, not mottled, length 62.9 μm (Fig. 24).

Specimens examined. TAIWAN: TAIPEI CITY: Neihu, 39 puparia, 1 third instar, 3 sec instars, 7 adult females, 3 adult males, 19 December 2005, C.H. Chen; KAOHSIUNG HSIEN: Taliao, 7 puparia, 21 March 2004, H.T. Yeh; TAITUNG HSIEN: Liyushan, 37 puparia, 17 adult females, 11 adult males, 23 February 2004, H.T. Yeh (all collected from *Oxalis corniculata*, NTU collection).

Host plants (based on Mound & Halsey 1978). Asteraceae: *Sonchus oleraceus* Linnaeus; Euphorbiceae: *Phyllanthus distinctus* (Linnaeus); Oxalidaceae: *Oxalis corniculata* Linnaeus, *Oxalis* sp.



Figures 25–26. Puparia of *Aleyrodes* spp. 25, *Aleyrodes proletella* (Linnaeus); 26, *Aleyrodes shizuokensis* Kuwana.



Figures 27–28. Vasiform orifice of *Aleyrodes* spp. adults. 27, *Aleyrodes proletella* (Linnaeus); 28, *Aleyrodes shizuokensis* Kuwana.

Distribution. Hawaii, India, Japan (based on Mound & Halsey 1978); Taiwan (Liyushan, Neihu and Taliao are new distribution records from Taiwan).

Biology. In Taiwan, this species is apparently restricted to members of the Oxalidaceae, especially on *Oxalis corniculata*, and is of no known economic importance. The puparia were often found in groups, heavily infesting the undersurfaces of leaves amid white wax, sometimes found together with *Bemisia tabaci*. Based on collection localities in Taiwan and distributions of the host plant, we believe this species might have a fragmentary distribution as seen in present records. According to Miyatake (1980), it completes several generations in a year. No ant attendance was observed.

Comments. Kuwana (1911) described the puparium and adults of *A. shizuokensis*, without making any remarks, and his observation on the adults' "eyes undivided, but deeply constricted about the middle" was erroneous. Takahashi (1951) made several diagnoses of the puparium in his work but did not make any comments either. Miyatake (1980) briefly described the puparium of *A. shizuokensis* and commented on its biology. His illustration is very interesting because the figure shows that there are 6 pairs of long setae on the dorsum. Comparison with the specimens in Taiwan suggests that they have 2 additional sites bearing long setae. David & Jesudasan (1989) redescribed the puparium of *A. shizuokensis*, "as the earlier descriptions of the species by Kuwana (1911), Singh (1931) and Rao (1958) are inadequate", but their description of the adult was still inadequate. In their work, the description and illustration of *A. shizuokensis* are almost identical to those of *A. proletella*, but no comments were made on this similarity.

Discussion

In terms of both the puparium and adults, *A. proletella* is very similar to *A. shizuokensis*. However, the puparium of *A. proletella* always has 3 pairs of dorsal setae: one cephalic, and one pair on each of abdominal segments I and VIII. In contrast, *A. shizuokensis* almost always has 4 pairs of dorsal setae, 3 pairs positioned as in *A. proletella* and an additional pair of metathoracic setae (Figs. 25, 26).

In the adults, the following differences were found: (1) *A. proletella* has no mottling on the pleurons, but *A. shizuokensis* is mottled on the head and meso- and metathoracic pleurons; (2) Only one tiny tubercle is situated at the interval between the compound eyes in *A. proletella* but two occur in this position in *A. shizuokensis* (Figs. 4, 16); (3) The metatibial comb of the female contains about 25 setae in *A. proletella* but only 20 in *A. shizuokensis* (Figs. 8, 20); (4) The lingula in *A. proletella* is nearly twice longer than that of *A. shizuokensis*; this is a significant diagnostic character (Figs. 27, 28); (5) In Taiwan, *A. proletella* always feeds on Asteraceae and *A. shizuokensis* on Oxalidaceae; the overlap of published host plant records may be the result of misidentifications due to the high level of puparial similarity between these species.

Host plant selection in Aleyrodes proletella *(Linnaeus). Aleyrodes proletella* usually feeds on Cruciferae in Europe, but tropical collections do not show the same trend. Martin (1999) recorded its occurrence on Asteraceae weeds in Australia, and all the records from Taiwan were on asteraceous hosts. This is remarkable, as in Taiwan there are many cabbage crops on the mountain sides at medium elevations and cruciferaceous weeds usually are planted for green fertilizer. However, we could not find *A. proletella* on cruciferous plants. Generally, variation in a population may

influence the host selection behavior. In addition, the selection of host species is also affected by natural enemies (Nebreda et al. 2005). Undoubtedly the climate preference, behavior, natural enemies and habitats etc. of the Taiwanese *A. proletella* population are not the same as those of the European population. *A. proletella* mostly infests cruciferaceous crops elsewhere, but we were unable to obtain more information on host suitability. We need to understand why *A. proletella* has different host preferences in Australia and Taiwan (Asteraceae) from those in Europe (Cruciferae).

A taxonomic account of adult characters. Traditionally, whiteflies have not been identified using characters of the adults alone, due to their uniformity of structure (Mound 1973, Bink- Moenen 1991). The vasiform orifice and genitalia of the adults was reported to show only slight differences (Bink-Moenen 1991). However, we found clear differences in the morphology of the vasiform orifices of *A. proletella* and *A. shizuokensis*.

Acknowledgments

We cordially thank C. H. Hsieh, H. T. Yeh, C. C. Liu and Y. T. Shih (NTU) for their kind assistance in collecting material. Thanks are due to Dan Chamberlin for English editing of the draft and to anonymous reviewers for valuable suggestions and corrections for improving the article. This paper was supported, in part, by grants (NSC91-2313-B-002-370 and NSC 92-2313-B-002-055) from the National Science Council, Taiwan.

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Received 31 Octorber 2006; Accepted 24 May 2007. Publication date 28 Sept 2007.