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SYSTEMATICS, MORPHOLOGY AND PHYSIOLOGY

Description of the Third-Stage Larva and Puparium of *Platycheirus* (*Carposcalis*) *chalconota* (Philippi) (Diptera: Syrphidae) with New Information About the Trophic Interactions and Larval Habitats

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Abstract

In this study, the third-stage larva and puparium of the copper-backed fly, *Platycheirus* (*Carposcalis*) *chalconota* (Philippi, 1865) are fully described using stereomicroscopy and scanning electron microscopy from material collected in peach orchards of central-west Argentina. The immature stages of *P. chalconota* were compared with the third-stage larva and puparium of the best-studied species in the genus *Platycheirus scutatus* (Meigen, 1822); as well as with the only known *Carposcalis* immature stages description available for the Neotropical region namely *Platycheirus stegnus* (Say, 1829). New data on trophic interactions and larval habitats are given: *P. chalconota* larvae were found feeding on the aphid's species *Uroleucon sonchi* (Linnaeus, 1767) (large sow thistle aphid) and *Hyperomyzus lactucae* (Linnaeus, 1758) (blackcurrant-sow thistle aphid) in low vegetation as *Sonchus oleraceus* (common sow thistle); the species was also found feeding on *Myzus persicae* (Sulzer, 1776) (green peach aphid) in high vegetation as *Prunus persicae* (L.) Stokes (Peach trees). The third larval stage and puparium of *P. chalconota* are described and illustrated for the first time improving substantially the knowledge about the immature stages and natural history of Neotropical *Platycheirus*, constituting also a baseline for future comparative morphological studies. Despite the efficiency of *P. chalconota* in the biological control of pests has not been assessed, we think that relevant data presented here can be used in pest management of peach orchards and suggest *P. chalconota* as an excellent candidate for future studies on the life cycle, prey consumption, efficiency, artificial rearing, and its potential importance as pollinators of Peach crops.

Keywords Syrphinae · Immature stages · Morphology · Predatory larva · Aphids prey · Host plants

Introduction

Platycheirus Le Peletier and Audinet-Serville, 1828, is a very speciose genus of flower flies (Diptera, Syrphidae) with about 220 known species (Vockeroth 1990; Thompson and Skevington 2014; Young et al. 2016). Although the genus is distributed in all biogeographic regions, except in the Afrotropic, a vast majority of species occur in the Holarctic region (Thompson and Skevington 2014). The current concept of *Platycheirus* comprises four subgenera: *Platycheirus* (*Carposcalis*) Enderlein, 1938, *Platycheirus* (*Pachysphyria*)

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Enderlein 1938, *Platycheirus* (*Platycheirus*), and *Platycheirus* (*Tuberculanostoma*) (Fluke, 1943) (Mengual 2020). Nevertheless, other species groups can be recognized based on adult morphological characters (Young et al. 2016). The subgenus *Carposcalis* corresponds to the *stegnus* species group as defined by Vockeroth (1990), characterized by fore and mid tibiae with a row of posterior black setae, faced slightly to distinctly produced ventrally in both sexes with pruinosity either with oblique ripples or punctures and with anterobasal corner of oral margin produced into a point (Young et al. 2016). This monophyletic subgenus includes 19 Nearctic species (Thompson and Skevington 2014) and only one known from the Palearctic region (Smit and Barkalov 2008). Fourteen species are present in the Neotropical region, distributed from Mexico to Chile and Argentina, and extending throughout the Andes mountain range and temperate regions of South America (Thompson et al. 1976, 2010; Thompson and Skevington 2014).

Regarding the natural history of *Platycheirus*, several species are polyvoltine, some are oligovoltine, and a few are univoltine (Goeldlin de Tiefenau 1974). The adults of many species are abundant in moist places with low vegetation such as swamps, lakeshores, and mesophytic forests (Speight 2020). The oviposition has been recorded on leaves of ground vegetation cover (Salveter 1998; Young et al. 2016). *Platycheirus* larvae are predators mostly on aphids (Rojo et al. 2003), although some species are facultative phytophagous associated with decaying organic matter (Davidson 1922; Goeldlin de Tiefenau 1974; Rotheray and Gilbert 2011). Larvae of many species are generalist predators in leaf litter and are rarely found on trees (Rotheray 1993). Several prey records have been published for *Carposcalis species* (Rojo et al. 2003). For instance, *Platycheirus* (*Carposcalis*) *obscurus* (Say, 1824) and *Platycheirus* (*Carposcalis*) *trichopus* (Thomson, 1869) were found feeding on pea aphid, *Acyrtosiphon pisum* (Harris, 1776) in *Pisum sativum* L. (Fabaceae) in the United States (Cooke 1963; Thompson and Simmonds 1965). Adults of *Platycheirus* (*Carposcalis*) *confusus* (Curran, 1925) were observed flying over the colonies of the balsam twig-aphid, *Mindarus abietinus* Koch, 1857, in *Abies balsamea* Mill. and *Abies fraseri* (Pursh) Poir (Pinaceae) in Canada (Kleintjes 1997). Neotropical species are considered predators on Sternorrhyncha (Hemiptera) (Thompson et al. 2010); however, the trophic interactions (plant-aphid-syrphid larva) remain poorly explored and documented in natural and agricultural habitats (Dziock 2005) (Table 1).

Most of the taxonomic work done for the genus *Platycheirus* and subgenus *Carposcalis* is based on adult morphology (Vockeroth 1990; Young et al. 2016); meanwhile, the immature stages have been poorly studied and the available larval information is scarce. Nevertheless, some morphological descriptions of immature stages have been published, principally based on third-stage larvae and puparia (Table 2). Some important morphological characters of the larval stages such as sensillae distribution (chaetotaxy) have been little studied in detail for *Platycheirus* species (Hartley 1961; Rotheray and Gilbert 1989, 1999), albeit the mention by Bhatia (1939) and Rotheray and Gilbert (1999) for the larva of *Platycheirus scutatus* (Meigen, 1822). For the subgenus *Carposcalis*, the posterior respiratory process (prp) of the Nearctic species *P*. (*Carposcalis*) *obscurus* was described by Heiss (1938). More recently, Greco (1998) gave details of the overall appearance and color patterns of larva and puparium of a *Carposcalis* species from Argentina, which he identified as belonging to the Nearctic species *Platycheirus* (*Carposcalis*) *stegnus* (Say, 1829).

Platycheirus (*Carposcalis*) *chalconota* (Philippi, 1865) is a Neotropical species occurring from northwestern to southwestern South America, mainly along the Andean Cordillera

Table 1 Known Neotropical trophic interactions (plant-aphid-syrphid) of *Platycheirus* (*Carposcalis*) species

Platycheirus (Carposcalis) species	Plant species	Aphid species	Larval sampling or larval rearing	Country	Author
Platycheirus (Carposcalis) sp.	*Hordeum vulgare* L., *Triticum aestivum* L	*Diuraphis noxia* (Kurdjumov, 1913)	+	Mexico	Robinson 1992
Platycheirus stegnus (Say, 1829)	*Glycine max* (L.), *Medicago sativa* L	*Schizaphis graminum* (Rondani, 1852)	+	Argentina	Greco 1995, 1997
Platycheirus fenestratus (Macquart, 1842)	Brassicaceae*, Solanaceae*	*Brevicoryne brassicae* (Linnaeus, 1758)	-	Chile	Zuñiga 1967
Platycheirus edwardsi (Shannon & Aubertin, 1933)	*Medicago sativa* L	*Acyrthosiphon pisum* (Harris, 1776)	+	Chile	López et al. 2012
Platycheirus chalconota (Philippi, 1865)	Brassicaceae*, Solanaceae*	*Brevicoryne brassicae* (Linnaeus, 1758)	-	Chile	Zuñiga 1967
Platycheirus (Carposcalis) sp.	*Medicago sativa* L	*Acyrthosiphon pisum* (Harris, 1776)	+	Chile	López et al. 2012

(+) = larvae sampling was carried out. (-) = larval sampling was not performed. * = several species from this family

Table 2 *Platycheirus* species with described immature stages

Platycheirus species	Eggs (length and shape)	Third-stage larva (color and shape)	Posterior respiratory process (Prp)	Puparium (color and shape)	Cephalopharyngeal skeleton
Platycheirus (Platycheirus) albimanus (Fabricius, 1781)	Scott (1939)	Dixon (1960)	Dixon (1960)		
Platycheirus (Platycheirus) clypeatus (Meigen, 1822)		Dixon (1960)	Dixon (1960)		
Platycheirus (Platycheirus) fulviventris (Macquart, 1829)		Rotheray and Dobson (1987) Rotheray (1993)	Rotheray and Dobson (1987)	Rotheray and Dobson (1987)	
Platycheirus (Platycheirus) hyperboreus (Staeger, 1845)	Fluke (1929)	Fluke (1929)	Fluke (1929)	Fluke (1929)	
Platycheirus (Platycheirus) immarginatus (Zetterstedt, 1849)		Dunn (1949)		Dunn (1949)	
Platycheirus (Platycheirus) manicatus (Meigen, 1822)	Dunn (1949)	Dunn (1949) Dixon (1960) Rotheray (1986)	Dixon (1960)	Dunn (1949)	
Platycheirus (Platycheirus) melanopsis Loew, 1856		Rotheray (1997)	Rotheray (1997)	Rotheray (1997)	
Platycheirus (Platycheirus) peltatus (Meigen, 1822)		Rotheray (1993)		Rotheray and Gilbert (1989)	
Platycheirus (Platycheirus) perpallidus Verrall, 1901	Metcalf (1917)	Metcalf (1917)	Metcalf (1917)	Metcalf (1917)	
Platycheirus (Platycheirus) podagratus (Zetterstedt, 1838)		Rotheray (1993)			
Platycheirus (Platycheirus) quadratus (Say, 1823)		Heiss (1938)	Fluke (1929) Heiss (1938)	Heiss (1938)	
Platycheirus (Platycheirus) scutatus (Meigen, 1822) *	Bhatia (1939)	Krüger (1926) Bhatia (1939) Dixon (1960) Rotheray (1986)	Bhatia (1939) Scott (1939) Dixon (1960)	Bhatia (1939) Scott (1939)	Bhatia (1939) Rotheray and Gilbert (1999)
Platycheirus (Carposcalis) obscurus (Say, 1824)			Heiss (1938)		
Platycheirus (Carposcalis) stegnus (Say, 1829) **		Greco (1998)		Greco (1998)	

* = the best morphologically studied species in the genus. ** = doubtful identity. Nearctic species that Greco (1998) recorded from Argentina, although there are not available specimens to corroborate the identification by the present authors

and in temperate areas (Fluke 1945; Thompson et al. 1976; Marinoni et al. 2007; Montoya 2016). Redescribed by Fluke (1945, 1957), this species is quite common in Argentina and Chile, and adults are found in natural ecosystems and agricultural crops throughout the year (Monzón et al. 2020). According to recent literature (Smith-Ramírez et al. 2016; Monzón and Ruz 2018; Monzón et al. 2020), adults of *P. chalconota* visit a wide variety of native [i.e., *Eucryphia cordifolia* Cav. (Cunoniaceae), *Buddleja globosa* Hope (Scrophulariaceae), *Stachys grandidentata* Lindl. (Lamiaceae), and *Chaentanthera* spp. (Asteraceae)] and exotic plants [e.g., *Taraxacum officinale* Wigg. (Asteraceae), *Raphanus sativus* L. (Brassicaceae), *Hypochaeris* spp. (Asteraceae), *Viburnum* spp. (Caprifoliaceae), *Prunus armeniaca* L., *Prunus cerasus* L., *Prunus persicae* (L.) Stokes, and *Prunus domestica* L. (Rosaceae)] in both native and urban areas.

So far only one prey has been reported for *P. chalconota*, the cabbage aphid *Brevicoryne brassicae* (Linnaeus 1758) (Zúñiga 1967). Despite it is a common species found on several plant species, feeding on pest species and occurring through the whole year, the third-stage larva and puparium of *P. chalconota* are still unknown and the trophic interactions and larval habitat data have not been documented.

Based on the information above, this study aims to provide the first full description of the third-stage larva and puparium of *P. chalconota*, to inform about new records of trophic interactions (plant-aphid-syrphid larva), and to give new data on larval habitats of this species under field conditions.

Material and methods

Collecting sites

Fieldwork was carried out in Tupungato (Mendoza, Argentina) in two different peach orchards (33°19′47.3″S 69°08′40.3″W, 1166 m a.s.l and 33°19′43.5″S 69°09′16.5″W, 1186 m a.s.l.) during 2019. We searched for larvae once in each year season, i.e., autumn (March), spring (October), and summer (December) of 2019, as part of a larger study on flower fly biodiversity in organic peach orchards, where pupae and adults were also sampled.

Sampling and rearing

In each season, syrphid larvae (third-stage) were collected from low vegetation, mainly *Sonchus oleraceus* L. also known as common sow thistle (Asteraceae) (Fig S1 in the Online Resource), since these plants are found throughout the year (Ruiz Leal 1972) in peach orchards. A total of 40 plants per orchard were transferred to the Entomology Laboratory of Instituto Argentino de Investigaciones de Zonas Áridas (IADIZA), Mendoza, Argentina, in 30 × 40 cm plastic bags (four plants per bag). Afterwards, each plant was observed under a Leica S6D stereomicroscope, and each third-stage larva found was placed in 100 ml plastic containers sealed with 0.5 mm mesh screen and kept in a growth chamber (24–27 °C, RH 65 ± 4%) with natural light. Larvae were fed with aphids (Hemiptera: Aphididae) from the same colony where they were collected, in this case, the large sow thistle aphid, *Uroleucon sonchi* (Linnaeus, 1767) and the blackcurrant-sow thistle aphid, *Hyperomyzus lactucae* (Linnaeus, 1758). To maintain a constant flow of prey, every 48-h fresh plant parts with only aphids were placed inside 100 ml plastic containers until pupation. Each developed puparium was isolated in a Petri dish until the adult emerged. With this procedure, we corroborated that those larvae and puparia corresponded to *P. chalconota*. During October and early December, the same sampling and rearing method described above was applied on third-stage larvae found in shoots of peach trees, *Prunus persicae* with green peach aphids *Myzus persicae* (Sulzer, 1776) (Fig S2 in the Online Resource). The emerged adults (after 6–7 days of pupation) from sampled immatures were mounted on insect pins and identified using a key to Neotropical flower fly genera (Thompson 1999). Other available literature (Fluke 1945, 1957) was used to identify the adults to the species level. Adults identification was confirmed by comparison with specimens of the reference collection of the Instituto Superior de Entomología "Dr. Abraham Willink" (INSUE) Facultad de Ciencias Naturales, the Instituto Miguel Lillo, Universidad Nacional de Tucumán, Argentina, and Zoologisches Forschungsmuseum Alexander Koenig (ZFMK), Bonn, Germany. Flower flies identified as *P. chalconota* were selected for the present study (Figs. 1a, b and S3 in the Online Resource). All sampled flower flies were deposited in the entomological collection (CEI) of the Instituto Argentino de Zonas Áridas (IADIZA), Mendoza, Argentina.

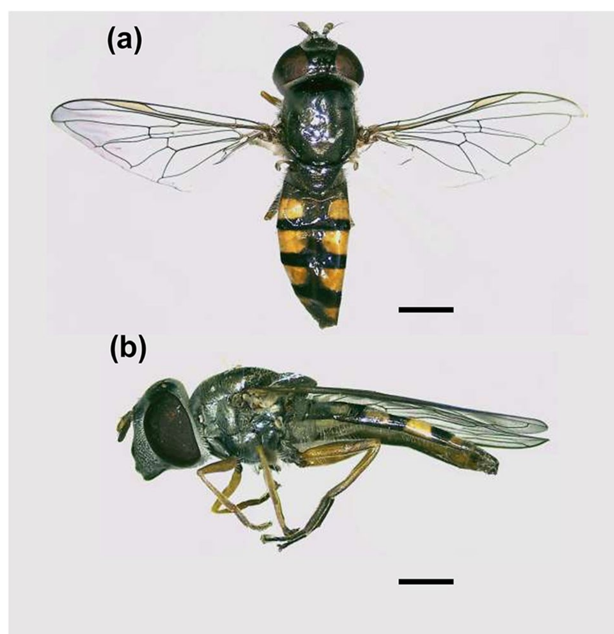


Fig. 1 *Platycheirus chalconotas* (Philippi 1865) female general habitus. **a** Dorsal view; **b** lateral view, scale bars = 1 mm

Morphological studies

To study color patterns in third-stage larvae and puparia, live specimens were photographed from a series of images taken at different focal depths using a Leica S6D stereomicroscope equipped with a Leica ES3 camera. In addition, some larvae were immersed in hot water (60 °C) for a few seconds, which allows preserving both fat tissue and color pattern (Rotheray 1993) to take photographs. Digital photographs were combined using the image-stacking freeware Combine ZP v. 1.0 (Hadley 2012). Cephalopharyngeal skeletons were obtained from the antero-ventral region of the puparia and then heated with 10% potassium hydroxide (KOH) for 4 min and preserved in glycerine. Illustrations of puparium segments and cephalopharyngeal skeleton were produced from optical images using a Leica MS5 stereomicroscope equipped with a camera lucida.

Ten third-stage larvae were selected for imaging with scanning electron microscopy (SEM). Larvae were fixed by immersion in water, slowly boiling for about 4 min. Simultaneously, the thorax was expanded pressing the first abdominal segment allowing a complete expansion of the body. Then, larvae were stored in 70% ethanol (Rotheray 1993). In order to take SEM images, larvae were gradually dehydrated using 25%, 50%, 75%, 90%, and 100% acetone (C_3H_6O) and later, critical-point dried in CO_2 with a Denton DCP-1 dryer. Five empty puparia were selected for writing the description. They were cleaned with an ultrasonic cleaner for 4 min to remove deposited debris on puparium tegument (Laska et al. 2006; Pérez-Bañón et al. 2013). Afterwards, larvae and puparia were mounted on standard stubs and coated with gold using a Denton Vacuum Desk IV coater. High-resolution images were obtained with a JSM-6610LV microscope (JEOL, www.jeol.com) at the Laboratorio de Microscopía Electrónica de Barrido y Microanálisis (MEByM), CONICET-Mendoza, Argentina. All measurements are stated in millimeters and micrometers. The illustration of the posterior respiratory process (prp) from third-stage larvae was done using SEM images.

The morphological terminology used for third stage-larva and puparium follows Rotheray and Gilbert (1989, 1999) and Rotheray (2019). The positions and numbering of sensillae from the dorsal to ventral surface on the larval segment follows Rotheray (1991), Pérez-Bañón (2000), and Laska et al. (2006), while sensillae numbering of the anal segment follows Pérez-Bañón (2000) and Laska et al. (2006). The pattern of segmental sensillae used was (Prothorax = ^{Pr}, Mesothorax = ^{Ms}, Metathorax = ^{Mt}, Abdominal = ^{A}).

Trophic interactions and larval habitats

New data about larval habitats of *P. chalconota* under field conditions were obtained from the fieldwork while sampling the larvae. Aphids collected from *S. oleraceus* and *P. persicae* were stored in 70% alcohol for morphological identification as prey of *P. chalconota*. Then, the aphids were sent to the Laboratorio de Entomología, Instituto Nacional de Tecnología Agropecuaria (INTA), EEA Junín, Mendoza. Aphid species were identified based on winged female adult morphology (Remaudiere and Seco Fernández 1990) and using a Zeiss Stemi 2000 C stereomicroscope. In addition, five specimens of each species were mounted using a modified protocol from the method by Eastop and Van Emden (1972). The mounting procedure consisted in to place the aphids in 10% potassium hydroxide (KOH); subsequently, heat in a boiling water bath for 5 min and then cool to 20 °C. After that, aphids were placed in 70% alcohol; the alcohol was removed and filled several times until the aphids were free of KOH. Once the washing process was finished, lightening liquid [equal parts of chloral hydrate ($C_2H_3Cl_3O2$) and phenol (C_6H_6O)] was added. Afterwards, the aphids were heated in a boiling water bath for 10 min, while the tube was shaken intermittently allowing the distribution of the lightening liquid into the aphids. A drop of Faure's liquid was placed directly onto the center of a glass microscope slide, and a specimen was mounted directly into the drop. A slide cover was then placed over the aphid, taking care to maintain aphid appendages in the proper orientation.

Results

Platycheirus (Carposcalis) chalconota (Philippi, 1865) (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and S3 in Online Resource).

Material examined

ARGENTINA: Nine third-stage larvae (on *Sonchus oleraceus* L.), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 15/III/2019, López-García and Mazzitelli Legs. (CEI). Seven third-stage larvae (on *Sonchus oleraceus* L.), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 15/III/2019, López-García and Mazzitelli Legs. (CEI). Ten puparia (on *Sonchus oleraceus* L.), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 15/III/2019, López-García and Mazzitelli Legs. (CEI). Five puparia (on *Sonchus oleraceus* L.), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 15/III/2019, López-García and Mazzitelli Legs. (CEI). Twelve third-stage larvae (on *Prunus persicae* L.), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 25/X/2019, López-García and Mazzitelli Legs. (CEI). Ten third-stage larvae (on *Prunus persicae* L.), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 25/X/2019, López-García and Mazzitelli Legs. (CEI). Fourteen third-stage larvae (on

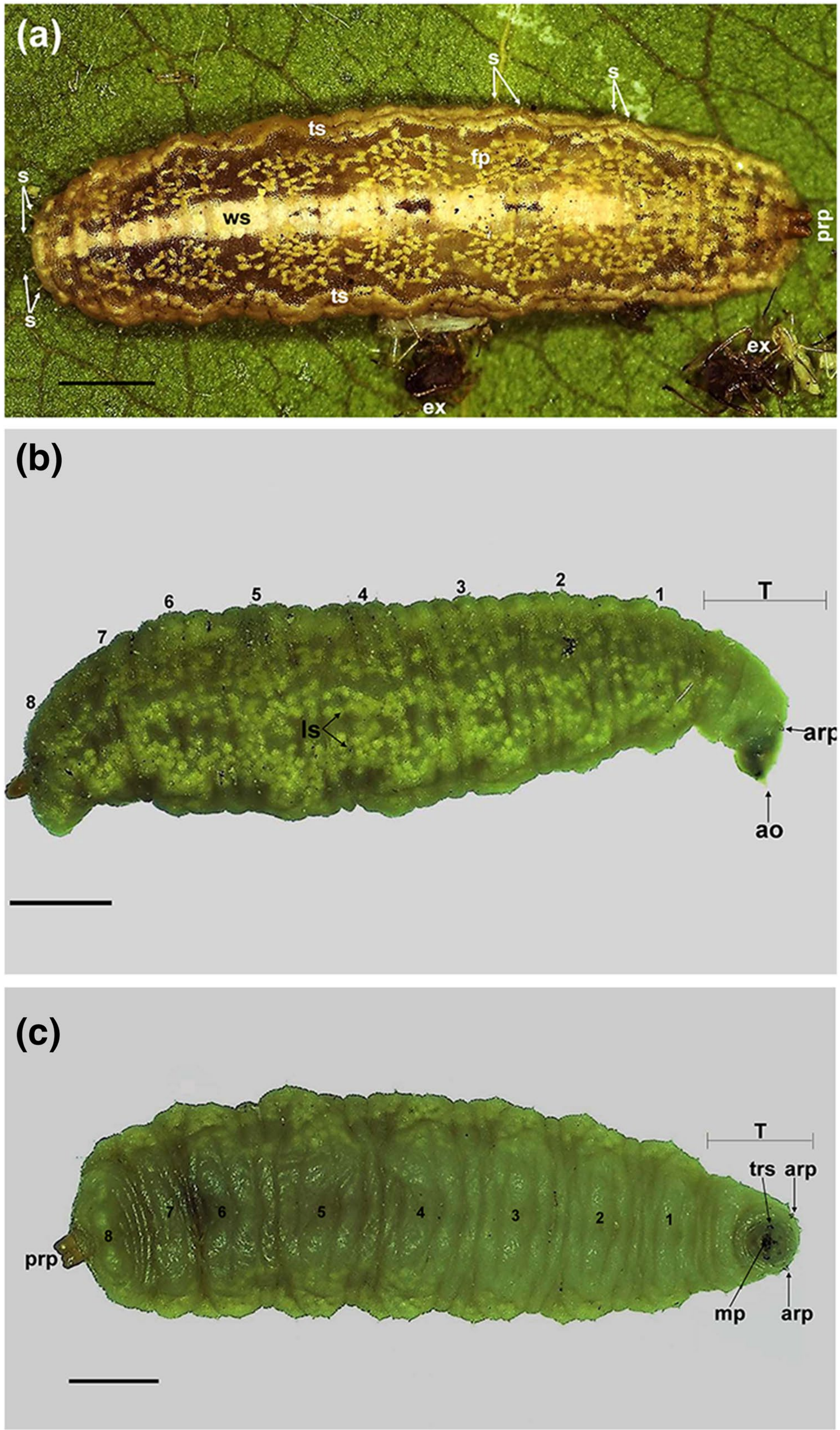


Fig. 2 Third-stage larva of *Platycheirus chalconota* (Philippi, 1865). **a** Dorsal view, note the median white stripe interrupted by black spots and thin black stripes; **b** lateral view; **c** ventral view, scale bar = 1 mm. (1 to 8) abdominal segments, (ao) antenno-maxillary organs, (apr) anterior respiratory process, (ex) aphid exuvia, (fp) green spots of fat particles, (ls) lateral stripes, (mp) mouthparts, (prp) posterior respiratory process, (s) sensilla, (tbs) thin black stripe, (trs) triangular sclerite, (ts) thin creamy white stripe, (ws) white stripe

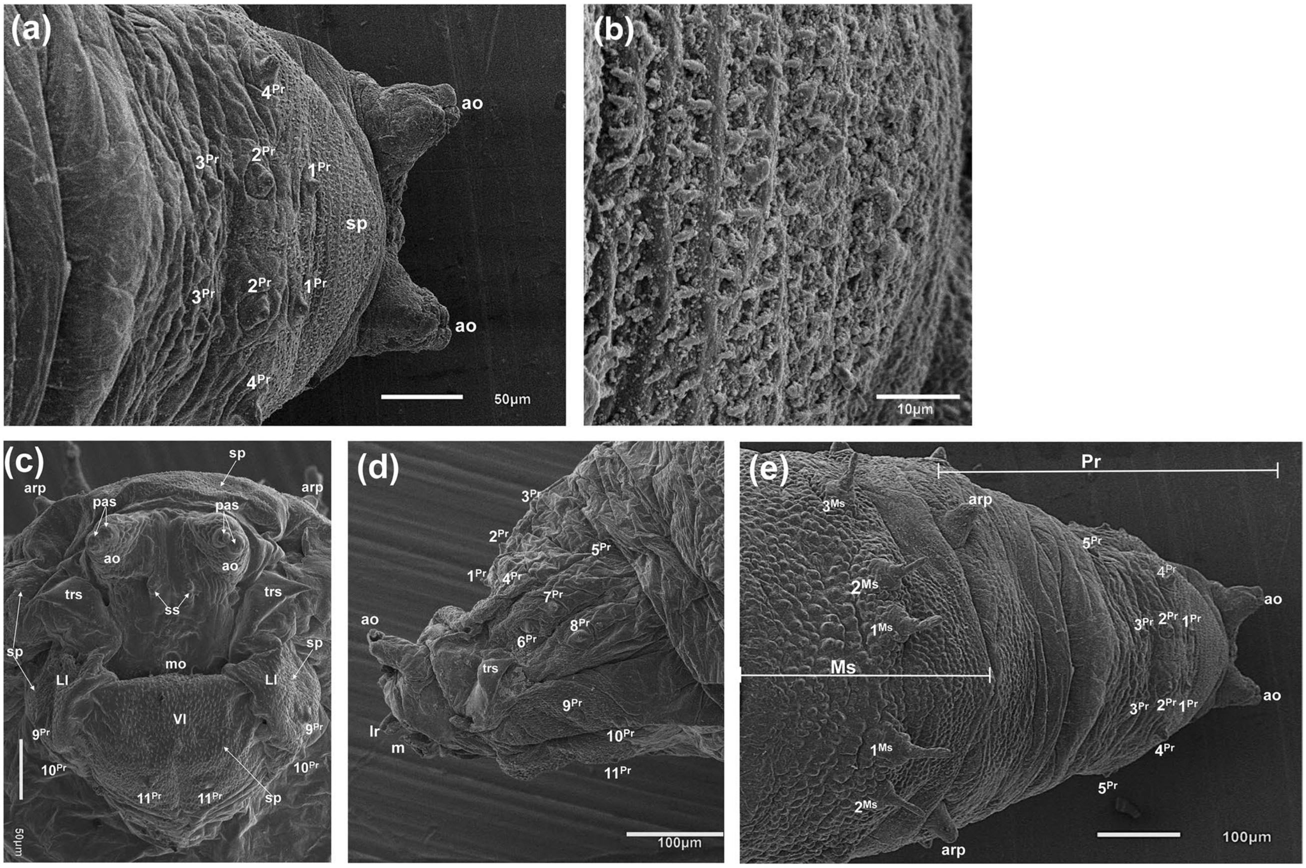


Fig. 3 Head and prothorax of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Dorsal view of head, antenno-maxillary organs, anterior fold with small spicules and papilliform sensillae; **b** details of small spicules; **c** head, front-ventral view, details of antenno-maxillary organs, small spicules, mouthparts, and sensillae without setae; **d** lateral view of prothorax, note the spatial distribution of papilliform sensillae without setae on prothorax; **e** differentiation between prothorax and mesothorax, note the spatial distribution of dorsal papilliform sensillae without setae on prothorax and mesothorax with sensillae with setae (segmental spines). (ao) antenno-maxillary organs, (arp) anterior respiratory process, (LI) lateral lips, (lr) labrum, (m) mandible, (mo) mouth opening, (Ms) mesothorax, (pas) papilliform sensillae on the top of antenno-maxillary organs, (Pr) prothorax, (sp) spicules, (ss) pair of small sensillae, (trs) triangular sclerite, (VI) ventral lips, (1^{Pr}–11^{Pr}) papilliform sensillae without setae

Prunus persicae L.), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 1/XI/2019, López-García and Mazzitelli Legs. (CEI). Eleven females (hand net), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 14/IX/2019, López-García Leg. (CEI). Twelve females (hand net), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 14/IX/2019, López-García Leg. (CEI). Eight males (hand net), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 14/IX/2019, López-García Leg. (CEI). Nine males (hand net), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 14/IX/2019, López-García Leg. (CEI). Nineteen females (hand net), Mendoza, Tupungato, 33°19′0.47.26″S, 69°08′0.40.27″W, 1166 m, 15/IX/2019, López-García Leg. (CEI). Thirteen females (hand net), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 15/IX/2019, López-García Leg. (CEI). Twenty-nine males (hand net), Mendoza, Tupungato, 33°19′0.43.45″S, 69°09′0.16.49″W, 1186 m, 15/IX/2019, López-García Leg. (CEI). One male (hand net), Mendoza, Ciudad, Zoólogico, 32°53′4.04″S, 68°53′19.719″W, 906 m, 4/VIII/1997, Roig and Debandi Legs. (CEI). One female (hand net), same data except 17/IX/1997. One male (hand net), Río Negro, El Tronador, 41°2′34.47″S, 70°59′47.499″W, 1193 m, 1/II/1946, Vellaro Leg. (INSUE). Two females, Santa Cruz, Lago Argentino, 41°22′30.112″S, 71°47′5.73″W, 764 m, 21/I/1953, Willink Leg. (INSUE).

Description of the third-stage larva

Color patterns, size, and shape Length 8–9 mm, width 2–2.3 mm, height 1.5–1.7 mm ($N = 10$). Sub-rectangular shape in cross-section, tapering anteriorly and slightly truncate posteriorly. Color pattern variable in ground color from green–brown to greenish with a median dorsal white-cream stripe from thorax until the sixth abdominal segment.

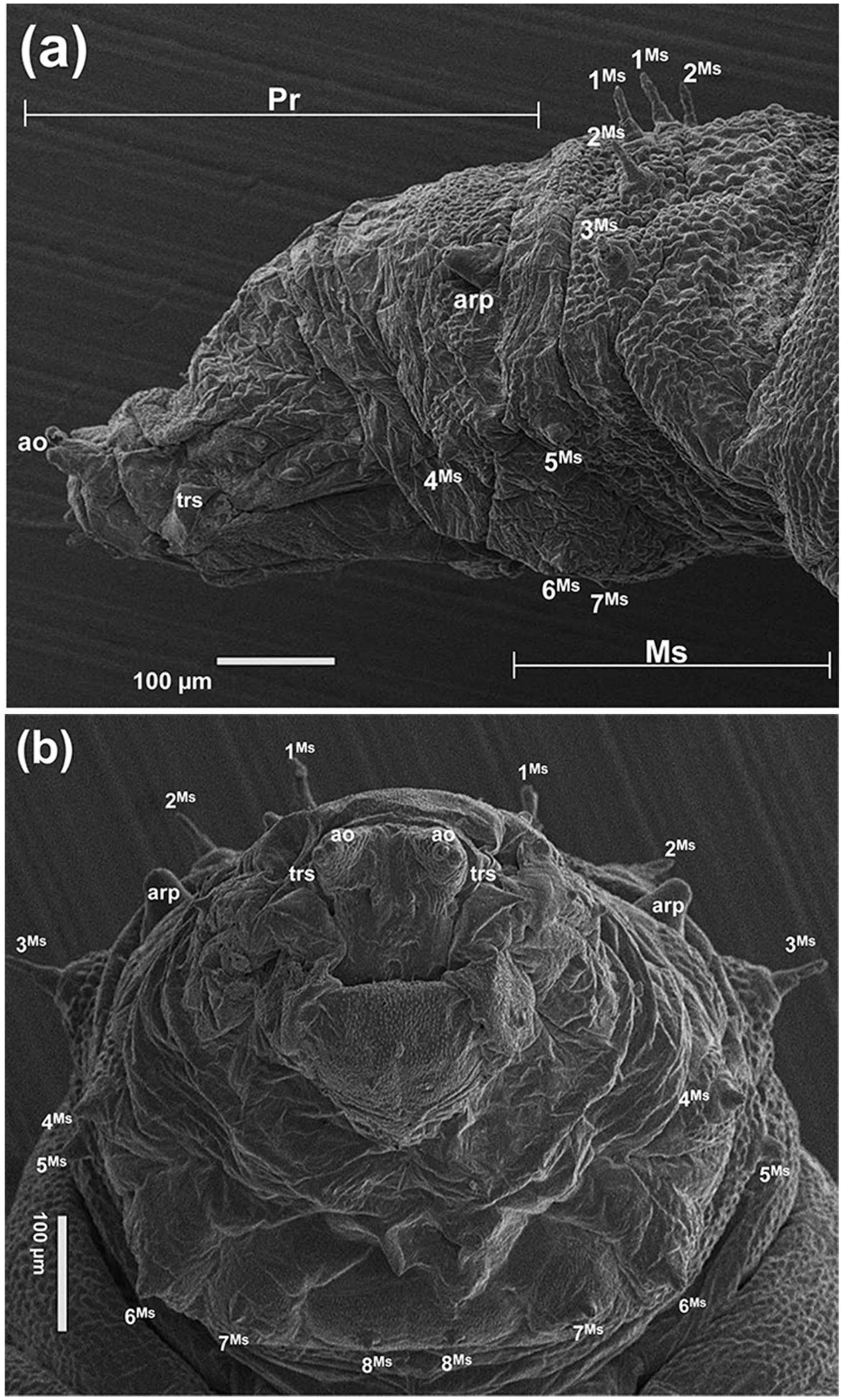


Fig. 4 Mesothorax of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Lateral view; **b** front-ventral view, spatial distribution of segmental spines, and sensillae without setae on mesothorax. (ao) antenno-maxillary organs, (arp) anterior respiratory process, (Ms) mesothorax, (Pr) prothorax, (trs) triangular sclerite, (1^{Ms}–3^{Ms}) dorsal segmental spines, (4^{Ms}–8^{Ms}) papilliform sensillae without setae

The black gut content is visible in the middle of the white-cream stripe as an interrupted background. Between the broad white stripe and lateral thin creamy white stripes, light green spots of fat particles are found throughout the entire larval body (Fig. 2a). The posterior respiratory process (posterior spiracle) is heavily sclerotized, as long as

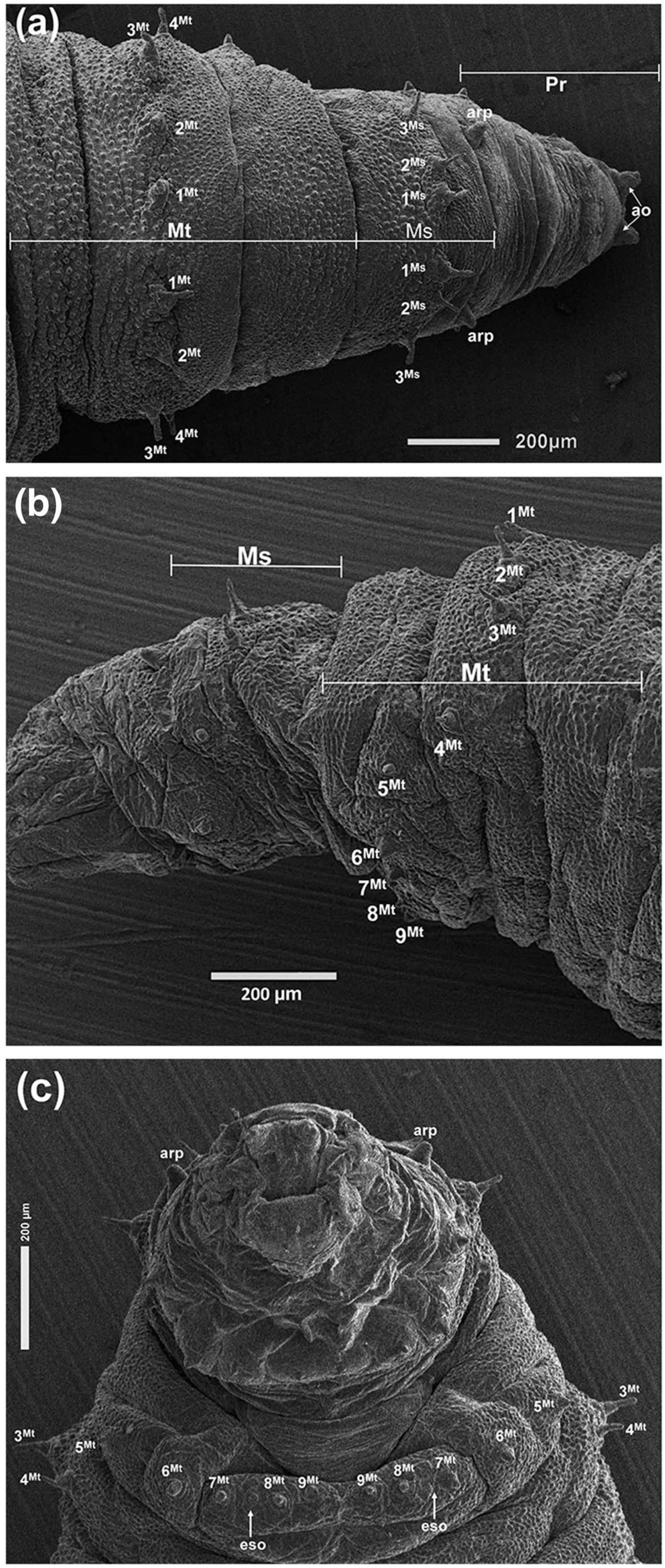


Fig. 5 Mesothorax of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Dorsal view, differentiation between metathorax, mesothorax, and prothorax, note the spatial distribution of dorsal segmental spines on metathorax; **b** lateral view and **c** ventral view, spatial distribution of segmental spines, and papilliform sensillae without setae on metathorax. (ao) antenno-maxillary organs, (arp) anterior respiratory process, (Ms) mesothorax, (Mt) metathorax, (Pr) prothorax, (1^{Mt}–4^{Mt}) segmental spines, (5^{Mt}–9^{Mt}) papilliform sensillae without setae

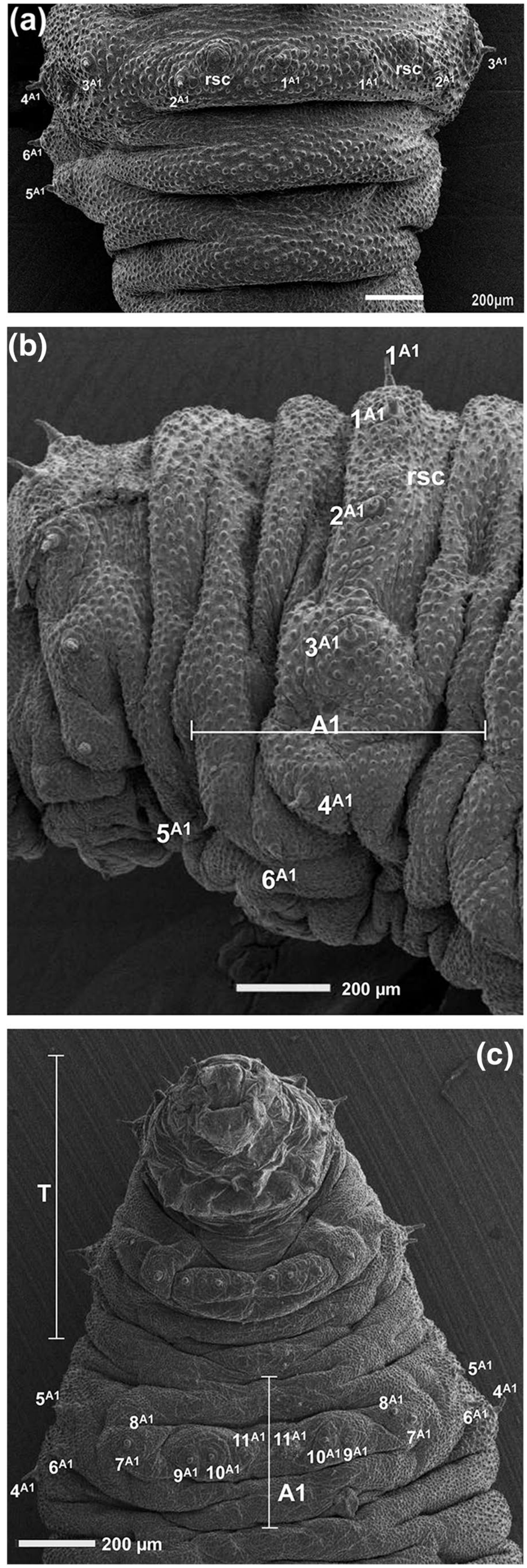


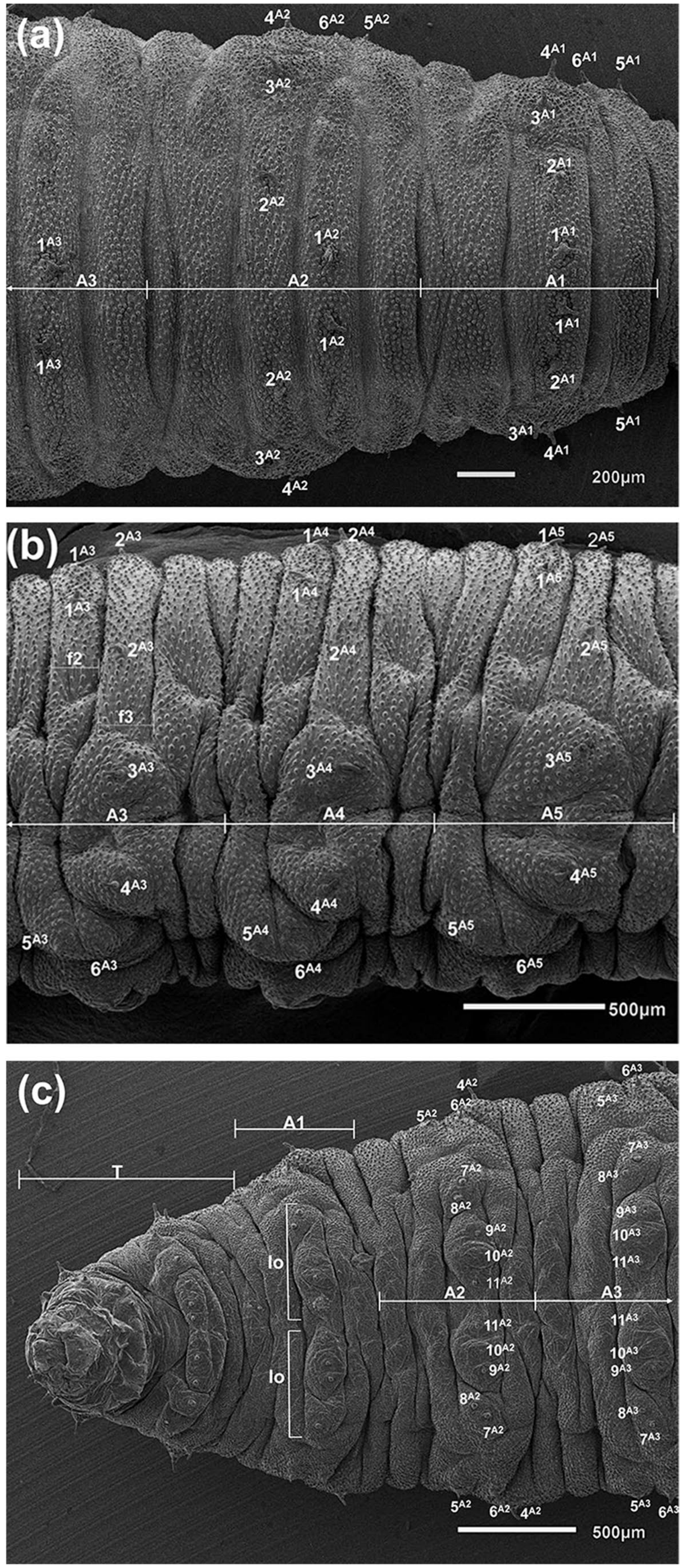
Fig. 6 First abdominal segment of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Dorsal view and **b** lateral view, spatial distribution of segmental spines on first abdominal segment; **c** ventral view, papilliform sensillae without setae on first abdominal segment. (A1) first abdominal segment, (rsc) round structure of differentiated cuticle, (T) thorax, (1^{A1}–6^{A1}) segmental spines, (7^{A1}–11^{A1}), papilliform sensillae without setae

broad, bronze-brown in color (Figs. 2a and S4 in the Online Resource), and with spiracular openings on a dark kidney-shaped plate. On the dorso-lateral surface, an accumulation of fat green pale spots forming two parallel bands or lateral stripes along the larval body can be observed (Fig. 2b). Ventrally, it is light green without color patterns (Fig. 2c). Prothorax and mesothorax are normally retracted into metathorax. Boundaries between segments obscured by secondary grooves and folds in the integument. Abdominal segments usually bearing five secondary folds. Integumental vestiture on cuticle consists in dome-shaped tubercles or sensillae, giving a papillose appearance. All body sensillae are light green or translucent and hardly visible by light stereomicroscope (Figs. 2a, b, c). The pattern of segmental sensillae (Pr, Ms, Mt) is very useful for orientation in primary segmentation, mainly the position of the dorsal sensillae of abdominal segments (A). Pairs 1 and 2 of segmental sensillae both located on the second fold in metathorax and first abdominal segment; in other abdominal segments, pair 2 of segmental spines are located just on the next fold.

Head Head very reduced (Figs. 3a, c, d, e). Mouthparts adapted for piercing-feeding (Hartley 1963) with distinctive features of predacious syrphid larvae. Lateral margins of mouth with a pair of black triangular pointed sclerites (Figs. 3c, d). Antenno-maxillary organs are well developed (Figs. 3a, c, d, e). Ultrastructure in SEM images showed many sensillae on top of the antenno-maxillary organs as in other aphidophagous larvae (Rojo et al. 2006). Under the antenno-maxillary organs, and above the mouth opening, there is a pair of small sensilla (Fig. 3c).

Thorax Prothorax with eleven pairs of sensillae without terminal seta (Fig. 3d). Dorsal papilliform segmental sensilla on prothorax are arranged in three transverse rows: the first one with two small sensilla (pair 1^{Pr}); the second one with four larger ones (pairs 2^{Pr} and 4^{Pr}); and the last one with four sensilla (pairs 3^{Pr} and 5^{Pr}) as small as those of the first row (Figs. 3a, d, e). Anterior fold of prothorax with a ring (covering < 20% of dorsal surface and < 35–40% of ventral surface) of small, sclerotized, backwardly directed spicules, which become progressively scarce posteriorly. On the dorsal surface of the prothorax, the spicules of the ring are more or less aligned in several transverse rows in front of the 1^{Pr} and 4^{Pr} segmental sensilla (Figs. 3a, b). Dorsal surface of prothorax with anterior respiratory process (anterior spiracle)

Fig. 7 The remaining abdominal segments of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Dorsal view, separation between abdominal segments, note the different spatial distribution of segmental spines between first and rest of abdominal segments; **b** lateral view, spatial distribution of segmental spines on third, fourth and fifth abdominal segments; **c** ventral view, spatial distribution of papilliform sensillae without setae on second and third abdominal segments. (A1) first abdominal segment, (A2) second abdominal segment, (A3) third abdominal segment, (A4) fourth abdominal segment, (A5) fifth abdominal segment, (f2) second fold, (f3) third fold, (lo) locomotory organs, (T) thorax, (1^{A2-7} on f2 and 2^{A2-7} on f3) segmental spines, (7^{A2-7}–11^{A2-7}) papilliform sensillae without setae



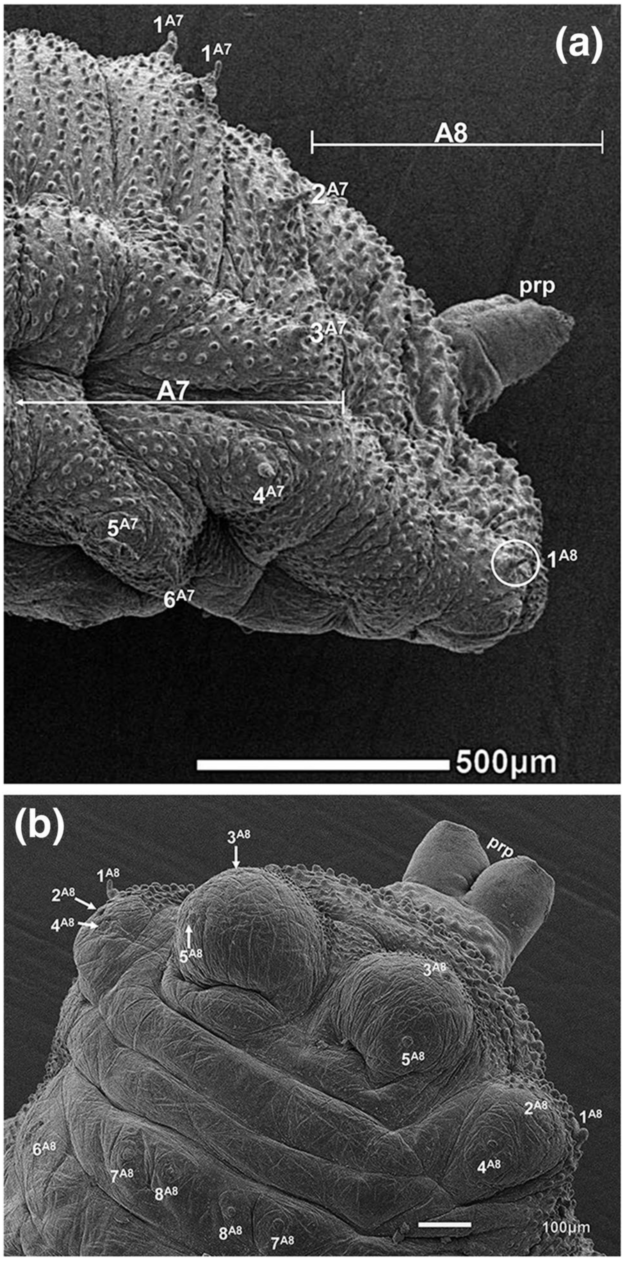


Fig. 8 Last abdominal segments of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a** Lateral view, spatial distribution of segmental spines on seventh and eighth abdominal segments, note a single pair on eighth segment. **b** Ventral view, spatial distribution of papilliform sensillae without setae on eighth abdominal segment. (A7) seventh abdominal segment, (A8) eighth abdominal segment, (prp) posterior respiratory process, (1^{A8}) one pair with setae, (2^{A8}–8^{A8}) papilliform sensillae without setae

short with cone-shape and with an opening on its anterior margin (Fig. 3e). Vestiture of prothorax above 4^{Pr} sensilla reduced, giving the integument a clear shining appearance.

The mesothorax with eight pairs of sensillae (Figs. 4a, b and 5a) arranged in two transverse rows: dorsal row with three dorsal pairs with terminal seta, also called segmental spines (pairs 1^{Ms}–3^{Ms}) and one dorso-lateral papilliform without seta (pairs 5^{Ms}); and ventral row located slightly anteriorly bearing four pairs of papilliform sensilla without setae (4^{Ms}–8^{Ms}). Metathorax with nine pairs of sensillae arranged in two main transversal rows: dorsal row with four pairs of segmental spines (pairs 1^{Mt}–4^{Mt}) and ventral row located slightly anteriorly with five pairs of papilliform sensilla without setae (pairs 5^{Mt}–9^{Mt}) (Figs. 5a, b, c). One extra pair of sensory organs (eso) near sensilla 7^{Ms} and 7^{Mt} (Fig. 5c).

Abdomen Abdominal segment with eleven pairs of sensillae. The first abdominal segment with six dorsolateral pairs with terminal seta or segmental spines (pairs 1^{A1}–6^{A1}) (Figs. 6a, b) and five ventral papilliform pairs without terminal seta (pairs 7^{A1}–11^{A1}) (Fig. 6c). Dorsal surface of the first abdominal segment with a pair of round structure of differentiated cuticle or circular patches (primordia of pupal spiracles) between sensilla pairs 1^{A1} and 2^{A1}. Dorsal pairs of segmental spines 1^{A1}–4^{A1} located on the same fold (Figs. 6a, b).

Second to seventh abdominal segments with the segmental spines 1^{A2-7} on the second fold and segmental spines 2^{A2-7} on third fold together with the segmental spines 3^{A2-7} and 4^{A2-7} (Figs. 7a, b). Locomotory organs are well developed; seven pairs present on abdominal segments 1–7 (Figs. 6c and 7c). On seventh abdominal segment, pair of segmental spines 1^{A7} separated from the base of prp by two folds, the posterior distinctly more developed (almost two times or more) and with vestiture (dome-shaped tubercles) enlarged in the medial area (Fig. 8a). The eighth abdominal segment with eight pairs of sensillae, only the first pair of dorsolateral with terminal seta (pair 1^{A8}) (Fig. 8a). The remaining seven pairs without setae and ventrally disposed (Figs. 8b and S5 in the Online Resource). Tip of the anal segment with two pairs of lobules in ventral view. Sensillae distribution is as follows: pairs 2^{A8} and 4^{A8} in small lateral lobules; pairs 3^{A8} and 5^{A8} in large central lobules; pairs 6^{A8}, 7^{A8}, and 8^{A8} located anteriorly separated from the pairs of lobules by two folds (Fig. 8b and Fig S5 in the Online Resource). The posterior third of the lobules covered by dome-shaped tubercles (Fig S5 in the Online Resource).

Posterior respiratory process Broader than long, it is situated on a tubular prominence with papillary texture (Figs. 8a, b). Spiracular plates are smooth and separated by a wide median groove with a nodular surface. There are two kidney-shaped surfaces in divergent positions concerning to the median groove and differentiated from the remainder of the spiracular plate. Each kidney-shaped surface contains three equidistant, elongated spiracular openings, and four short inter-spiracular setae (Figs. 9a, b).

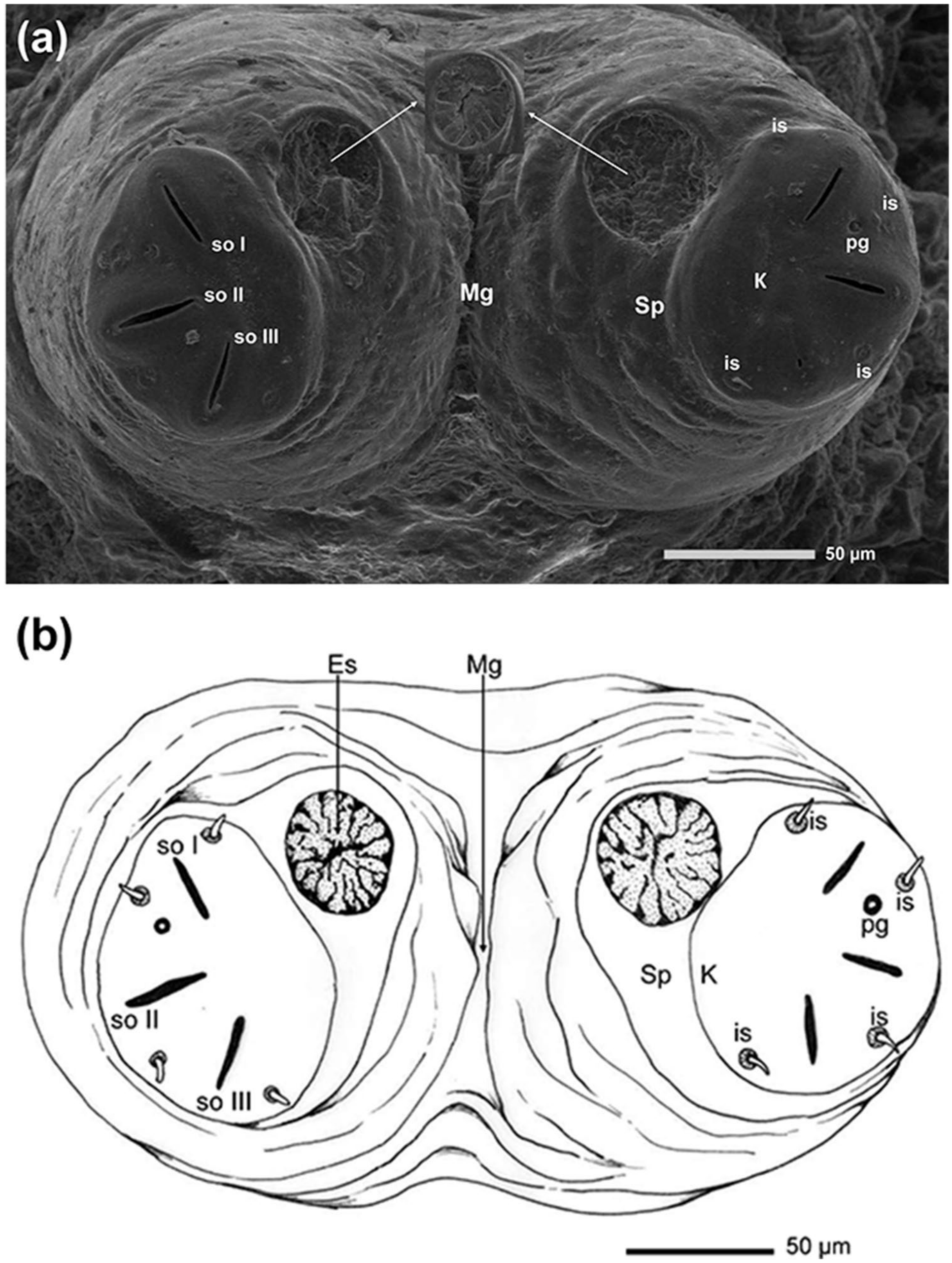


Fig. 9 Posterior respiratory process of third-stage larva of *Platycheirus chalconota* (Philippi, 1865) (SEM). **a–b** Front view of posterior respiratory process. (Es) ecdysial scar, (is) interspiracular setae, (K) kidney-shaped surfaces, (Mg) median groove, (pg) perispiracular glands, (so I–III) spiracular openings, (Sp) spiracular plates

These setae (Fig S6 in the Online Resource) (about one-third the length of the spiracular opening) are found between spiracular openings, from anterior to posterior edge of the kidney-shaped surface. Between spiracular opening I and II, there is a small round structure or perispiracular gland near the short seta. Round ecdysial scars are located at the same height as spiracular opening I in anteromedial position to the kidney-shaped surface. It has a diameter of approximately one and a half to twice the length of a spiracular opening (Figs. 9a, b). Inside the spiracular opening, brush-shaped structures can be observed (inner serrations or trabeculae) (Fig S6 in the Online Resource).

Description of puparium

Overall appearance Length 5.5–6 mm; width 2–2.4 mm; height 2–2.2 mm ($N=5$). Color from light to dark brown with very dark brown spots or markings caused by pigmented cuticle. Laterally in some specimens, dark spots forming a zigzag stripe are found. The posterior end is dark brown with a bronze-brown posterior spiracle. It is oval in outline from dorsal view and flattened ventrally from the lateral view. Segmentation is hardly distinctive through light stereomicroscope; transverse grooves and folds are fine and equally spaced; longitudinal folds and large structures are

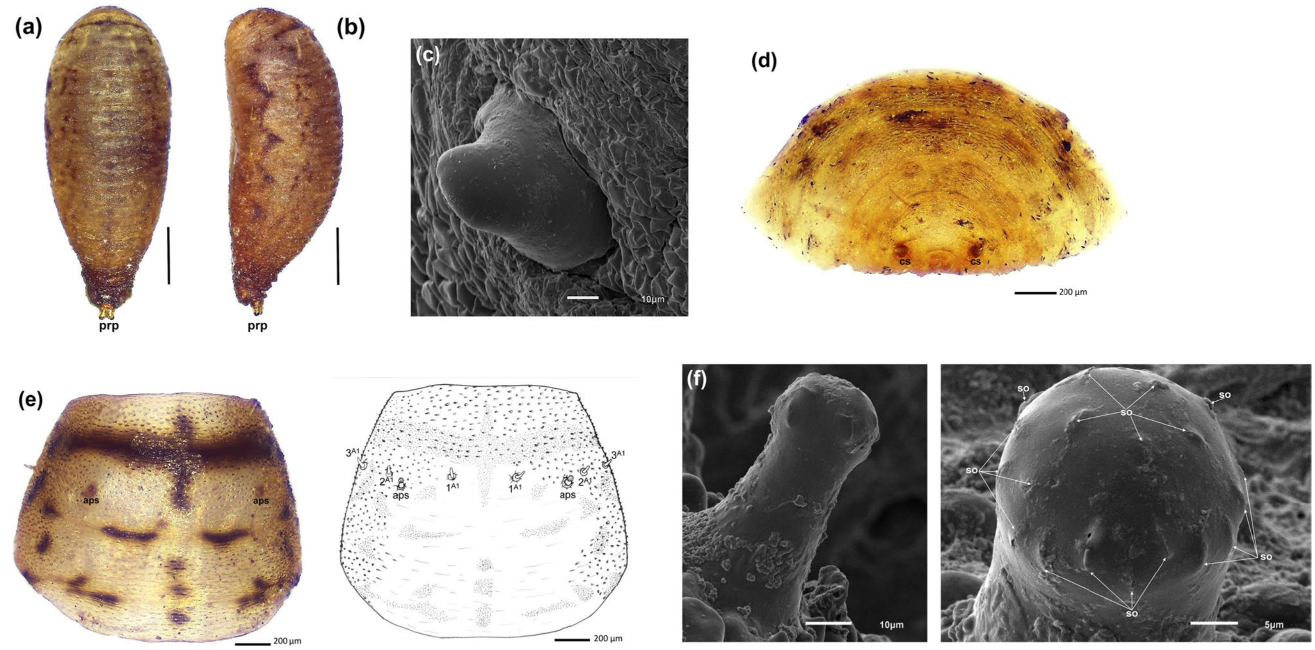


Fig. 10 Puparium of *Platycheirus chalconota* (Philippi, 1865). **a** Dorsal view and **b** lateral view, scale bars = 1 mm; **c** conical structures, these correspond to anterior respiratory process (anterior spiracles) in the third-stage larva (SEM). **d** Front view, prothorax, mesothorax, and metathorax of puparium, spatial distribution of translucent papilliform setae and brown conical structures; **e** front view, the first abdominal segment of puparium, spatial distribution of translucent papilliform setae and brown anterior pupal spiracle; **f** anterior pupal spiracle and spiracular openings. (aps) anterior pupal spiracle, (cs) conical structure, (prp) posterior respiratory process, (1^{Ms}–3^{Ms}, 1^{Mt}–3^{Mt}, 1^{A1}–3^{A1}) papilliform setae, (so) spiracular openings

absent, and texture is papillose (Figs. 10a, b). Setae distribution is as follows: from frontal view of puparium, on prothorax, a pair of conical structures or pupal horns corresponding to anterior spiracles of third-stage larva are found (Fig. 10c). There are also three pairs of setae on papillae corresponding to dorsal sensillae on mesothorax of third-stage larva (Fig. 10d). Above these, three pairs of setae on papillae are observed, which coincide with the metathorax section of third-stage larva (Fig. 10d). The first abdominal segment of puparium contains three pairs of setae on papillae. Between setae pairs 1 and 2, there is an anterior pupal spiracle corresponding to a patch of differentiated cuticle in third-stage larva (Fig. 10e). Pupal spiracle is brown in color (Fig. 10e) and cylindrical in shape with a rounded tip. Spiracular openings (more than twenty) are radially located on spiracle edges, and some are located in the center of the pupal spiracle (Fig. 10f). The remaining abdominal segments are similar in general setae distribution to third-stage larva.

Cephalopharyngeal skeleton It is a dark chitinous structure. From the lateral view, it contains sclerotized and elongated mandibles with a sharp tip. Sclerotized labrum is slightly broader with a rounded tip. Labium is also sclerotized with a sharp tip. Dorsal cornu is rounded on the top margin and almost straight on the lower margin. Tentorium extends from dorsal to ventral cornu. Ventral cornu is elongated with inner and outer wings. Inner wings have straight margins (Fig. 11).

Trophic interactions

The first aphid species collected on *S. oleraceus* was identified as *Uroleucon sonchi* (Linnaeus, 1767) (Remaudiere and Seco Fernández 1990; Carver 1999) (Fig S7 in the Online Resource). The second aphid species collected on *S. oleraceus* was identified as *Hyperomyzus lactucae* (Linnaeus, 1758). (Remaudiere and Seco Fernández 1990) (Fig S8 in the Online Resource). The aphid species collected on *P. persicae* was identified as *Myzus persicae* (Sulzer, 1776) (Remaudiere and Seco Fernández 1990; Devi and Singh 2007) (Fig S9 in the Online Resource).

Larval habitats

Larvae of *P. chalconota* were found in high and low vegetation. In high vegetation or fruit trees such as *P. persicae*, syrphid larvae fed on green aphid *M. persicae* (new trophic interaction) during spring (October and early December) (Fig. 12). In low vegetation such as *S. oleraceus*, third-stage larvae of *P. chalconota* fed on aphids *U. sonchi* and *H. lactucae* (new trophic interaction) during autumn (March),

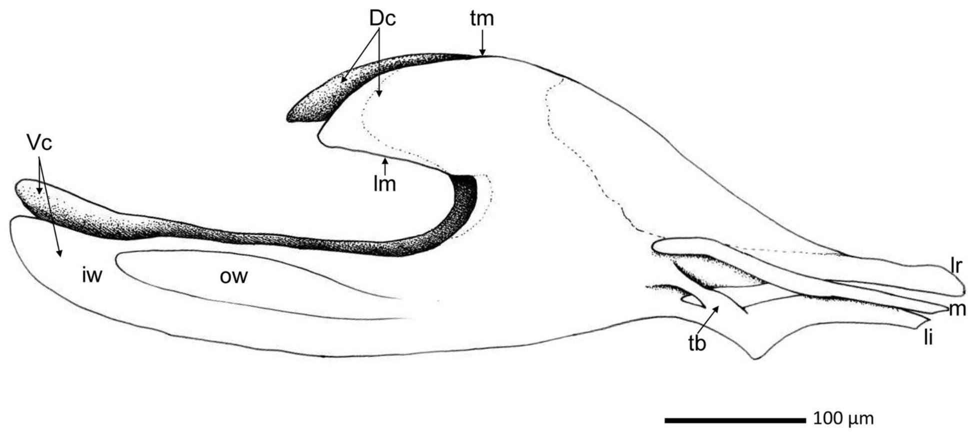


Fig. 11 Cephalopharyngeal skeleton of *Platycheirus chalconota* (Philippi, 1865). (Dc) dorsal cornu, (lm) low margin of dorsal cornu, (tm) top margin of dorsal cornu, (Vc) ventral cornu, (iw) inner wing of ventral cornu, (ow) outer wing of ventral cornu, (li) labium, (lr) labrum, (m) mandible, (tb) tentorial bar

Fig. 12 Habitats of third-stage larvae of *Platycheirus chalconota* (Philippi, 1865). **a** High vegetation (peach trees); **b** low vegetation

spring (October), and summer (December) in organic peach orchards of central-west Argentina.

Discussion

Despite a large number of *Platycheirus* species, only a handful of immature stages of several species have been described (Table 2). The third-stage larva of *P. chalconota* described here has the diagnostic characteristics for *Platycheirus* proposed by different authors (Dixon 1960; Rotheray and Gilbert 1989): sub-rectangular shape; variable color pattern due to fat body forming chevrons, dorsal and lateral stripes formed by fat; papillose cuticle with dome-shaped tubercles or papillae; the tip of anal segment with two pairs of lobes forming locomotory organs; posterior spiracle with spiracular openings on a white or black area differentiated from the remainder of spiracular plates; and interspicular ornamentation of short setae.

The distinguishing characteristics of *P. chalconota* larvae are a broad dorsal white stripe interrupted by black spots and thin black stripes (variable in number), thin creamy greenish stripes on each dorsolateral side, green spots of fat particles on the whole dorsal surface, and bronze-brown posterior spiracle (Figs. 2a, b, c); posterior spiracle with brown spiracular plates with dark kidney-shaped surfaces divergent in position concerning the median groove, each one with three equidistant spiracular openings and four short inter-spiracular setae; and round ecdysial scars with a diameter one and a half to twice the length of a spiracular opening (Figs. 9a, b). Regarding the puparium, the one of *P. chalconota* can be differentiated from other *Platycheirus* puparia by its dark brown spots on the dorsal surface and dark brown spots forming a zigzag stripe on the lateral side (Figs. 10a, b); plus, the morphology of the mesothorax, metathorax, first abdominal segment, and anterior pupal spiracle (Figs. 10d, e, f).

Larvae of *P.* (*Carposcalis*) *chalconota* (Figs. 2a, b, c) are very similar to the ones of *P*. (*Platycheirus*) *scutatus* in overall appearance (Rotheray 1993: Fig. 4e) as both have greenish larvae of similar size and the eighth abdominal segment (Figs. 8a, b and S5 in the Online Resource) has the same sensillae distribution pattern (Rotheray and Gilbert 1999: Fig. 19E). They differ in that *P. scutatus* larvae have dorsal triangular markings or cream pink chevrons directed forwards and cream pink dorsolateral stripes, a posterior spiracle with inter-spiracular setae, and spiracular openings situated on the pale, almost semi-circular surface (Bhatia 1939: Fig. 47, Dixon 1960; Rotheray 1986). In *P. chalconota* larvae, the dorsal stripe is white with black spots and thin black stripes (Fig. 2a), and inter-spiracular setae and spiracular openings are situated on a kidney-shaped surface on the posterior spiracle (Figs. 9a, b).

The puparia of *P. chalconota* and *P. scutatus* are also similar in overall appearance and size, both with transverse grooves, fine folds equally spaced, and no longitudinal folds and large cuticular structures (Figs. 10a, b, Bhatia 1939: Fig. 46, Scott 1939: Fig. 1, Plate XXIX). However, they differ in coloration pattern: *P. scutatus* puparium is light and shiny (Scott 1939) whereas *P. chalconota* puparium is brown with dorsal dark brown spots and lateral dark spots forming a zigzag stripe (Figs. 10a, b). The cephalopharyngeal skeleton of *P. scutatus* has a labrum with a sharp tip, mandibles with a broader tip, and a labium with a sharp tip (Bhatia 1939: Fig. 44, Rotheray and Gilbert 1999: Fig. 16B). In contrast, *P. chalconota* has a labrum slightly broader with a rounded tip, mandibles with sharp tips, and the same labium (Fig. 11).

Greco (1998) described superficially the larvae of a *Carposcalis* species from the province of Buenos Aires, Argentina. In his previous work based on the same material, Greco (1995) identified this taxon as *Platycheirus carposcalis* (L.), but this taxon does not exist. Later, Greco (1998) identified this taxon as *P.* (*Carposcalis*) *stegnus*, a Nearctic species occurring along the West Coast from British Columbia south to Mexico and, so far, not recorded in South America. Fluke (1945) already stated that the records of *P. stegnus* from South America by Enderlein (1938) certainly refer to other Neotropical species, either *Platycheirus* (*Carposcalis*) *punctulatum* (Wulp, 1888), or *P.* (*Carposcalis*) *fenestratum* (Macquart, 1842). This may also be the case for the records of Greco (1995, 1998). The identity of the material studied by Greco (1995, 1998) could not be corroborated as the material was not available for this study. Nevertheless, the color patterns of third-stage larvae of *P. chalconota* and the *Carposcalis* species described by Greco (1998) are similar, presenting a greenish to light brown body color with a dorsal discontinuous white stripe interrupted by black spots. The puparia of these taxa show different color patterns: the puparium of the *Carposcalis* taxon by Greco (1998) has orange spots and the one of *P. chalconota* has dark brown spots.

Other *Platycheirus* species, mentioned in Table 2, are distinguishable from *P. chalconota* due to the general color of larvae and dorsal patterns of chevrons, as well as by the morphology of the posterior spiracle. Most of the published descriptions of *Platycheirus* immature stages are poor in detail, making it difficult to distinguish them from other species. Yet, the most profusely described character, and usually illustrated, is the posterior respiratory process (prp) on the spiracular plates. Based on the location of the spiracular openings on the spiracular plates, a character already used by Dixon (1960), the known *Platycheirus* species with described immature stages can be clustered into two main groups: species with equidistant spiracular openings in the prp and those with spiracular openings II nearer to III than to I. Although our knowledge about immature stages for *Platycheirus* is very limited, it is worth to point out that the species with equidistant spiracular openings in the prp (i.e., *P. chalconota*, *P. clypeatus*, *P. fulviventris*, *P. hyperboreus*, *P. obscurus*, *P. perpallidus*, *P. quadratus*, and *P. scutatus*) belong to the *albimanus* group (in the subgenus *Platycheirus*) and *stegnus* group (= subgenus *Carposcalis*) characterized by Vockeroth (1990). All the *Platycheirus* species listed above within the *albimanus* group belong to the *clypeatus* subgroup and to the *scutatus* complex as defined by Young et al. (2016). The taxa with spiracular openings II nearer to III than to I (*P. albimanus*, *P. manicatus*, and *P. melanopsis*) belong to the *albimanus* and *manicatus* subgroups of the *albimanus* group as outlined by Vockeroth (1990).

We can conclude that *P. chalconota* is a polyvoltine species as immatures and adults were found in peach orchards of central-west Argentina in different seasons of the year. Moreover, its larvae feed on different prey on different plants as reported in this study. The three aphid species recorded in our study as prey of *P. chalconota* are different from the literature records (Zúñiga, 1967) or from the pest species used to feed other *Carposcalis* species in laboratory conditions, i.e., *Acyrthosiphon pisum* (Harris, 1776) (López et al. 2012). This polyphagy may explain the presence of *P. chalconota* around the year and its abundance. Our results provide new information about the natural history of *P. chalconota* and constitute the first genuine record of trophic interactions (plant-aphid-syrphid larva) for this species.

The present work improves substantially the knowledge about the immature stages and natural history of Neotropical *Platycheirus* and is the baseline for future comparative studies based on morphology. Despite the efficiency of *P. chalconota* in the biological control of pests has not been assessed, we think that relevant data presented here can be used in pest management of peach orchards and suggest *P. chalconota* as an excellent candidate for future studies on the life cycle, prey consumption, and efficiency, including the development of artificial rearing as well as the evaluation of its potential importance as pollinators of Peach crops.

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Declarations

Ethics approval Not applicable for that section.

Consent to participate Not applicable for that section.

Consent for publication Not applicable for that section.

Conflict of interest The authors declare no competing interests.

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