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Redescription of *Conostigmus albovarius* Dodd, 1915 (Hymenoptera, Megaspilidae), a metallic ceraphronoid, with the first description of males

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Abstract
Conostigmus albovarius Dodd, 1915 (Hymenoptera: Megaspilidae) is a species previously known by a single female holotype. Here, we provide a redescription of this peculiar ceraphronoid based on several female specimens and describe the male of the species for the first time. Intraspecifically-variable morphological traits such as female antenna color pattern are documented and discussed. A phenotype bank of morphological characters is provided for use in future megaspilid taxonomic treatments. We also provide phenotypic data in a semantic form to allow for ease of data integration and accessibility, making taxonomic data more accessible to future systematic efforts.

Keywords
Ceraphronoidea, morphology, systematics, taxonomy

Introduction

Conostigmus Dahlbom, 1858 (Hymenoptera: Ceraphronoidea; Megaspilidae) is a relatively small genus of parasitoid wasps that has been largely neglected by modern taxonomic efforts, though they are commonly collected and are worldwide in distribution (Johnson and Musetti 2004). Relatively little is known about the biology of *Conostigmus*

(Graham 1984, Bijoy et al. 2014). However, the superfamily Ceraphronoidea is known to contain both endoparasitoids and ectoparasitoids, with examples of both known to occur even within the same genus (Mikó et al. 2013; Broad and Livermore 2014).

Ceraphronoids have been reared from hosts spanning a large variety of orders, including Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Mecoptera, Neuroptera, Thysanoptera, and Trichoptera (Schaffner 1959; Dessart 1967; Graham 1984; Dessart 1992; Goulet and Huber 1993; Mikó and Deans 2009). Information about the specific hosts of *Conostigmus* is limited: Kamal (1926) reports two species, *Conostigmus triangularis* Thomson, 1858 and *C. timberlakei* Kamal, 1926, as reared from Syrphidae (Diptera) puparia. Vidal (2003) reports that *Conostigmus rufescens* Kieffer, 1907 is known to parasitize the eggs and larvae of the brassica pod midge, *Dasineura brassicae* Winnertz, 1853 (Diptera: Cecidomyiidae), which is a pest of rapeseed (*Brassica napus* L. 1753). While species such as *C. rufescens* could be economically important, research efforts are hampered because so little work has been done on the systematics of Ceraphronoidea (Vidal 2003; Mikó et al. 2013).

Alan P. Dodd described the species *Lygocerus albovarius* from a single female specimen he captured in Australia (Dodd 1915). Dodd later expressed doubts on being able to distinguish between females of *Conostigmus* and *Lygocerus* after discovering the male of another Australian species he had described from a female specimen, *Conostigmus unilineatus* Dodd 1915. He advised that all of the Australian species he had described from female specimens, including *L. albovarius*, were more likely to be *Conostigmus* (Dodd 1916). Paul Dessart initially transferred *Lygocerus albovarius* from *Lygocerus* to *Dendrocerus* (Dessart, 1972), but later transferred the species to *Conostigmus* following the suggestion of Dodd (Dessart 1995; Dessart 1997).

Materials and methods

Air-dried point-mounted specimens were obtained from the Canadian National Collection of Insects (CNC). To prepare specimens for dissection, air-dried point-mounted specimens were removed from their points, cleared with BioQuip Specimen Clearing Fluid #6373, and subsequently kept in glycerol for dissection and storage. Dissections were performed with #2 insect pins and #5 forceps.

Air-dried point-mounted specimens and glycerol-stored specimens were examined using an Olympus SZX16 stereomicroscope with an Olympus SDF PL APO 1X PF objective (115×) and an Olympus SDF PL APO 2X PFC objective (230× magnification). Blue-Tack (Bostik, Inc., Wauwatosa, Wisconsin, USA) was used to stabilize specimens while making observations and images. Measurements were taken using a KR 851 stage micrometer (1mm in 100 divisions) attached to the same microscope. Bright field images were taken with an Olympus DP71 digital camera attached to an Olympus ZX41 compound microscope. Images were subsequently aligned and stacked using Zerene Stacker Version 1.04 Build T201404082055.

For the male and female species descriptions, 87 morphological characters were scored based on observations of air-dried point mounted specimens and glycerol stored specimens. Following the Phenotypic Quality Ontology (PATO; available at http://obofoundry.org/), the preferred label "count" was used instead of its synonyms, including "presence". It logically follows that the character "presence" should not include "absent" as a state because the correct use of this syntax would be "presence/absence: absent", which would over-complicate descriptions. Specimen data, OTU concepts, natural language phenotypes and images of specimens were compiled in the MX database (http://mx.speciesfile.org). This software was used to render the Diagnosis, Description, and Material Examined sections. Definitions and descriptions of the morphological terms and structures were mapped to classes in the following phenotype-focused ontologies: Hymenoptera Anatomy Ontology (HAO), Phenotypic Quality Ontology (PATO), Biospatial Ontology (BSPO), OBO Relation Ontology (RO), Ontology for Biomedical Investigations (OBI), and Information Artifact Ontology (IAO), all available at http://www.ontobee.org/ (Xiang et al. 2011).

Semantic statements were generated in Protégé Version 5.0.0 (Build beta-17) to build an ontology where phenotypes are represented semantically. Standardizing taxonomic data through ontology-based semantic representation could benefit future systematic work by allowing taxonomic data sets from different sources to be easily integrated, expediting computerized searches across these data sets (Deans et al. 2012; Balhoff et al. 2013; Mikó et al. 2014). Statements were written in OWL Manchester syntax, modeled after examples set by Balhoff et al. (2013), Mikó et al. (2014), and Mikó et al. (2015). A list of the semantic statements generated is presented in Supplementary file 1: Appendix 1. The data matrix file, the NEXUS file corresponding to the data matrix and the semantic annotations file are available at http://dx.doi.org/10.6084/m9.figshare.1539620, http://dx.doi.org/10.6084/m9.figshare.1544551, and http://dx.doi.org/10.6084/m9.figshare.1539621.

Taxonomy

Conostigmus albovarius (Dodd, 1915)

Figs 1–6

Lygocerus albovarius: Dodd, A. P. 1915: 453 (original description)
Conostigmus albovarius: Dodd, A. P. 1916: 18
Dendrocerus albovarius: Dessart, P. 1972: 291
Conostigmus albovarius: Dessart, P. 1995: 320
Conostigmus albovarius: Dessart, P. 1997: 7, 133

Diagnosis. *Conostigmus albovarius* differs from all other Megaspilidae by the presence of metallic coloration and foveolate sculpturing.

Redescription. Color and sculpture. Color hue pattern male: cranium, mesosoma, F1-9, pedicel, distal region of hind femur, abdomen brown; scape, forelegs and midlegs, tibia of hind leg yellow; hind coxa and petiole neck white. Color hue pattern female: cranium except supraclypeal depression and mesosoma except posteroventral region metallic brown/purple; F9, distal and proximal region of scape, supraclypeal depression, abdomen, dorsal proximal regions of femur and tibia brown; F1-F5, pedicel, scape except distal and proximal regions, posteroventral region of mesosoma, petiole neck white; F6-F8 variable white or brown. Foveolate sculpture on body count: present on mesosoma and frons; present on frons. Occipital carina sculpture: crenulate.

Head morphometrics. Cephalic size (csb): Mean: 300–450 μm. Head height (lateral view) vs. eye height (anterior view): HH:EHf = 1.0–2.0. Head height vs. head length: HH:HL = 1.0–1.5. Head width vs. interorbital space: HW:IOS = 2.0–2.5. Head width vs. head height: HW:HH = 1.0–1.5. Male ocular ocellar line vs. lateral ocellar line: OOL:LOL = 1.0–2.0. Male ocular ocellar line vs. posterior ocellar line: OOL:POL = 0.5–2.0. Female ocular ocellar line vs. lateral ocellar line: OOL 1.5–2.5 × as long as LOL.

Head and antenna. Median flange of occipital carina count: absent. Submedial flange of occipital carina count: absent. Dorsal margin of occipital carina vs dorsal margin of lateral ocellus in lateral view: occipital carina is ventral to lateral ocellus in lateral view. Preoccipital lunula count: present. Preoccipital carina count: present . Preoccipital furrow count: present. Preoccipital furrow anterior end: Preoccipital furrow ends inside ocellar triangle. Postocellar carina count: absent. Transversely reticulate region on frons count: present. Transversely reticulate region on frons extent: restricted to lateral branches of supraclypeal depression. Rugose region on frons count: absent. White, thick setae on frons count: present. Ventromedian setiferous patch and ventrolateral setiferous patch count: absent. Antennal scrobe count: absent. Facial pit count: no external corresponding structure present. Supraclypeal depression count: present. Supraclypeal depression structure: absent medially, represented by two grooves laterally of facial pit. Intertorular area count: present. Intertorular carina count: present. Median region of intertorular area shape: flat. Transverse frontal carina count: absent. Ventral margin of antennal rim vs dorsal margin of clypeus: not adjacent. Torulo-clypeal carina count: present. Subtorular carina count: absent. Mandibular tooth count: 2. Female first flagellomere length vs pedicel: F1 as long as pedicel (1.0–1.1). Female ninth flagellomere length: F9 less than F7+F8; F9 = F7+F8. Male first flagellomere length vs male second flagellomere length: 1.0–1.1. Length of setae on male flagellomere vs. male flagellomere width: setae shorter than width of flagellomeres; setae as long as width of flagellomeres. Sensillar patch of the male flagellomere pattern: F5–F9.

Mesosoma and metasoma. Ventrolateral invagination of the pronotum count: present. Anterior mesoscutal width vs. posterior mesoscutal width: AscW/PscW = 0.8–0.9. Mesoscutal length vs anterior mesoscutal width: MscL/AscW = 1.0–2.0. Weber length: WL = 400–550 μm. Notaulus posterior end location: adjacent to transscutal articulation. Median mesoscutal sulcus posterior end: adjacent to transscutal articulation. Scutoscutellar sulcus vs transscutal articulation: adjacent. Axillular carina count:

absent. Speculum ventral limit: not extending ventrally of pleural pit line. Epicnemial carina count: complete. Epicnemium posterior margin shape: anterior discrimenal pit absent; epicnemial carina curved. Sternaulus count: present. Sternaulus length: short, not reaching 1/2 of mesopleuron length at level of sternaulus. Mesometapleural sulcus count: present. Metapleural carina count: present. Transverse line of the metanotum-propodeum vs. antecostal sulcus of the first abdominal tergum: adjacent sublaterally. Lateral propodeal carina count: present. Lateral propodeal carina shape: straight (left and right lateral propodeal carinae compose a carina that is not broken medially). Anteromedian projection of the metanoto-propodeo-metapecto-mesopectal complex count: absent. Posterior margin of nucha in dorsal view shape: concave. Transverse carina on petiole shape: concave.

Abdomen and male genitalia. S1 length vs. shortest width: S1 wider than long. Distal margin of male abdominal sternum 9 shape: straight. Proximolateral corner of abdominal sternum 9 shape: blunt. Cupula length vs. gonostyle-volsella complex length: cupula less than 1/2 the length of gonostyle-volsella complex in lateral view. Proximodorsal notch of cupula count: present. Proximodorsal notch of cupula shape: arched. Distodorsal margin of cupula shape: straight. Proximodorsal notch of cupula width vs length: wider than long. Proximolateral projection of the cupula shape: blunt. Distoventral submedian corner of the cupula count: absent. Dorsomedian conjunctiva of the gonostyle-volsella complex count: present. Dorsomedian conjunctiva of the gonostyle-volsella complex length relative to length of gonostyle-volsella complex: dorsomedian conjunctiva extending 2/3 of length of gonostyle-volsella complex in dorsal view. Distal end of dorsomedian conjunctiva of the gonostyle-volsella complex shape: acute. Parossiculus count (parossiculus and gonostipes fusion): present (not fused with the gonostipes). Apical parossiculal seta number: one. Distal projection of the parossiculus count: absent. Distal projection of the penisvalva count: absent. Dorsal apodeme of penisvalva count: absent. Harpe length: harpe shorter than gonostipes in lateral view. Distodorsal setae of sensillar ring of harpe length vs. harpe width in lateral view: setae as long or shorter than harpe width. Distodorsal setae of sensillar ring of harpe orientation: medially. Sensillar ring area of harpe orientation: medially. Lateral setae of harpe count: present. Lateral setae of harpe orientation: oriented distally.

Material examined. Specimens (3 males, 7 females): AUSTRALIA: 3 females. PSUC_FEM 35246, 45237, 83872. AUSTRALIA: Queensland: 3 males, 4 females. PSUC_FEM 36035, 45221, 45227, 45257, 84276, 91442, 98392. A full list of the locality data for each specimen is provided in Table 1.

Specimens will be deposited at the Canadian National Collection of Insects (CNC), Ottawa, ON, Canada and at the Frost Entomological Museum (FEM), University Park, PA, USA.

Comments. *Conostigmus albovarius* stands out from other species of *Conostigmus* due to its unique, white color pattern, for which the species was named (*albus* as in "white" and *varius* as in "variegated") (Dessart 1997). Dessart (1997) was intrigued by the stark white color present on the back of the mesosoma and on portions of the legs and antennae. He attributed the unique color of the antenna and legs to a lack of pig-

Figure 1. Bright field image of *Conostigmus albovarius* (Dodd, 1915) female. **A** Head and antennae, lateral view showing antennae and scape coloration (see http://dx.doi.org/10.6084/m9.figshare.1539641) **B** Habitus lateral view showing a variation in antennae coloration (see http://dx.doi.org/10.6084/m9.figshare.1539639).

ment in these areas, but voiced concerns whether the color of the mesosoma could be an artifact due to damage of the sole holotype specimen (Dessart 1997). With the discovery of ten new specimens, it is now clear that this coloring of the mesosoma is not an artifact, and that it is a phenotype shared by both females and males of the species (Figs 1, 2, 3).

Another phenotype that both males and females share is the presence of foveolate sculpturing, a feature which has not been described before in *Conostigmus*. Most mem-

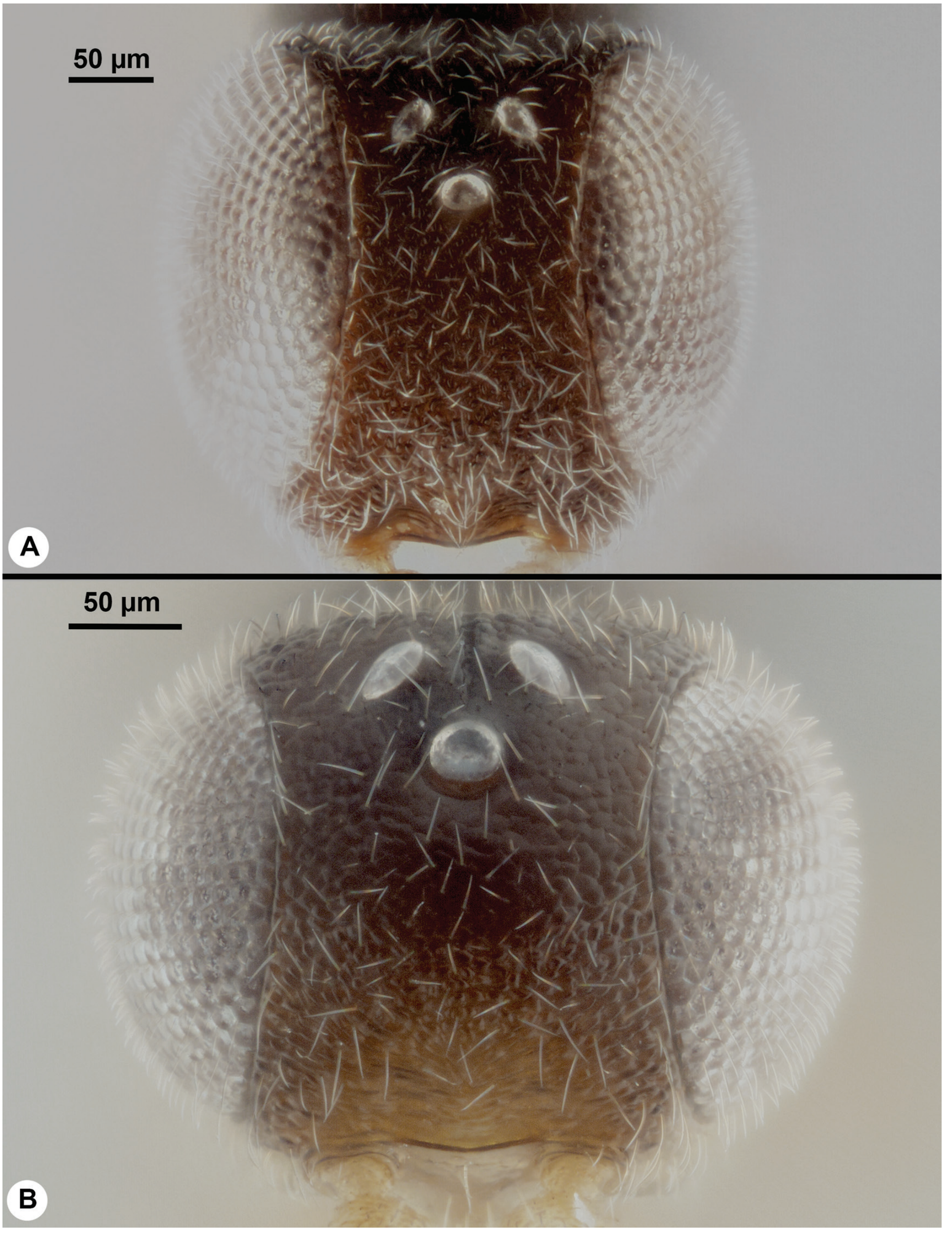

Figure 2. Bright field images of *Conostigmus albovarius* (Dodd, 1915). **A** Female head and frons, anterior view (see http://dx.doi.org/10.6084/m9.figshare.1539640) **B** Male head and frons, anterior view (see http://dx.doi.org/10.6084/m9.figshare.1539642).

bers of *Conostigmus* exhibit reticulate sculpturing (Yoder et al. 2010), which refers to the polygonal microreticulation of the cuticular surface that is most likely based on the pattern of epithelial cells (Krell 1994).

Figure 3. Bright field images of *Conostigmus albovarius* (Dodd, 1915) male habitus, lateral view (see http://dx.doi.org/10.6084/m9.figshare.1539644).

Table 1. A list of the locality data for the specimens examined.

Materials examined	
Specimen ID	**Locality data**
PSUC_FEM 98392	Australia: QLD: Wooroonooran National Park 17°34'09"S; 145°46'35"E: 375m, 25.ix.2004 s.s. L. Masner, rainforest, Q-28
PSUC_FEM 45257	Australia: QLD: Wooroonooran National Park 17°34'09"S; 145°46'35"E: 375m, 25.ix.2004 s.s. L. Masner, rainforest, Q-28
PSUC_FEM 91442	Australia: QLD: Wooroonooran National Park 17°34'09"S; 145°46'35"E: 375m, 25.ix.2004 s.s. L. Masner, rainforest, Q-28
PSUC_FEM 45237	Australia: QLD: Tully River Falls Road Misty Mountains Trail 12.IX.2004, s.s. Q-11 L. Masner, rainforest
PSUC_FEM 36035	Australia: QLD: Wooroonooran National Park: 17°34'06"S; 145°42'21"E: 500m, 9-14.ix.2004 YPT L. Masner, rainforest, Q-7a
PSUC_FEM 35246	Australia: QLD: Tully River Falls Road Misty Mountains Trail 12.IX.2004, s.s. Q-11 L. Masner, rainforest
PSUC_FEM 83872	Australia: QLD: Tully River Falls Road Misty Mountains Trail 12.IX.2004, s.s. Q-11 L. Masner, rainforest
PSUC_FEM 45221	Australia: QLD: Wooroonooran National Park: 17°34'06"S; 145°42'21"E: 500m, 9-14.ix.2004 YPT L. Masner, rainforest, Q-7a
PSUC_FEM 84276	Australia: QLD: Wooroonooran National Park: 17°34'06"S; 145°42'21"E: 500m, 9-14.ix.2004 YPT L. Masner, rainforest, Q-7a
PSUC_FEM 45227	Australia: QLD: Ella Bay Nat. Park 17°28'14"S, 146°03'48"E 21–23.IX.2004 YPT L. Masner, rainforest, Q-23

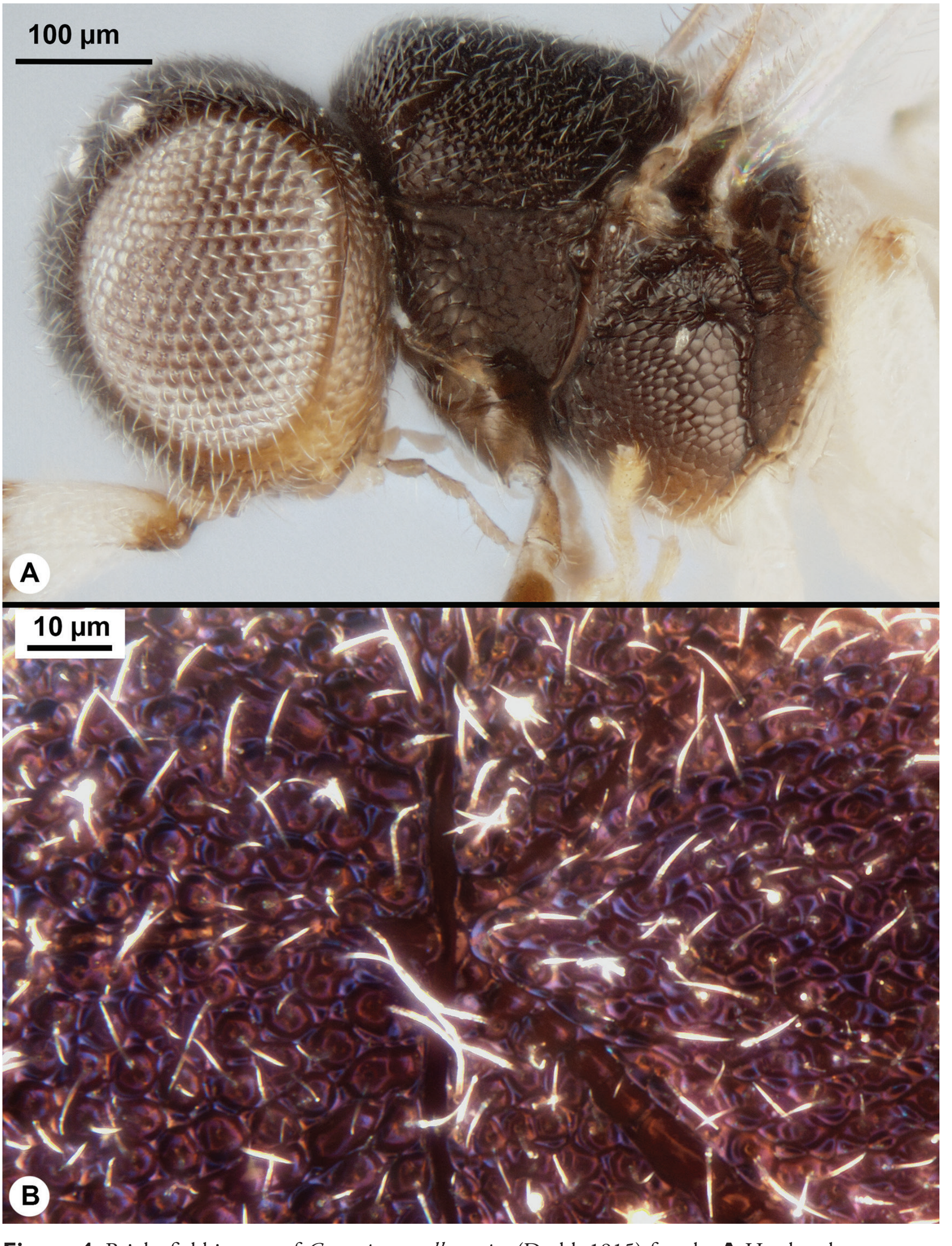

Figure 4. Bright field images of *Conostigmus albovarius* (Dodd, 1915) female. **A** Head and mesosoma, lateral view (see http://dx.doi.org/10.6084/m9.figshare.1539643) **B** Posterior mesoscutum and anterior mesoscutellum showing areolate sculpture and metallic coloration (see http://dx.doi.org/10.6084/m9.figshare.1539645).

Figure 5. Bright field images of *Conostigmus albovarius* (Dodd, 1915) male. **A** Head and mesosoma, dorsal view (see http://dx.doi.org/10.6084/m9.figshare.1539647) **B** Head and mesosoma, lateral view (see http://dx.doi.org/10.6084/m9.figshare.1539646).

Figure 6. Bright field images of *Conostigmus albovarius* (Dodd, 1915) male genitalia. **A** Dorsal view (see http://dx.doi.org/10.6084/m9.figshare.1539648) **B** Ventral view (see http://dx.doi.org/10.6084/m9.figshare.1539649).

C. albovarius, in contrast, exhibits foveolate sculpturing. Our definition of foveolate sculpturing is based on Harris (1979), where the cuticle is divided into irregular pits with raised edges and a single seta is present at the center of each pit. In females, foveolate sculpturing is present on the head and mesosoma, while in males the foveolate sculpturing is only present on the frons. In females, the areas with foveolate sculpturing are also present with a metallic coloration ranging from a bronze sheen to a deep iridescence (Fig. 4). This metallic coloration is absent from males.

In comparing the antennae of different female specimens, it was observed that there was variation in the coloration of the apical flagellomeres (Fig. 1). Whereas F9 is always melanized and F1 through F4 always have transparent cuticle (it appears white because of the soft tissue, e.g. fat bodies and muscles, underneath), F5 through F8 vary in whether melanization is present or not. When melanization is present, it is always present in the apical flagellomeres after the melanized flagellomere, such that if F5 is melanized, then F6–9 will also be melanized. It is unclear whether this intraspecific phenotypic variation in color is influenced by genetic or environmental factors, such as temperature (Quicke 1997). Females from different sampling events in different areas sometimes shared the same pattern of melanization on the antennae, though females collected from the same sampling event sometimes had different patterns.

It is known that the antennae play important roles in the courtship of parasitic wasps in general (Ayasse et al. 2001; Romani 2008). In *Cotesia rubecula* (Hymenoptera: Braconidae), females use their antennae to signal their receptivity to the males (Field and Keller 1993). It is possible that the melanization seen in female *C. albovarius* antennae could be used for visual signaling to males during courtship.

Author contributions

Conceived the project: IM. Character concept generation, semantic statement generation, specimen visualization and creation of plates: CT, IM. Specimen measurements: CT. Wrote the manuscript: CT. Commented on the final stage of the manuscript: ARD, IM.

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Supplementary material 1

Semantic representation of phenotypic character states

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Data type: Table

Explanation note: A complete list of the phenotypic character states used and their corresponding semantic representations.