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Research paper

# Annuli and setal patterns in the flagellum of female micro-whipscorpions (Arachnida: Schizomida): Hypotheses of homology across an order

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ABSTRACT

Schizomid female flagellum, including the number of "flagellomeres" and the setae, are among the most important taxonomic characters within the order. It is widely used to diagnose genera within both extant families. Despite the traditional use in schizomid taxonomy, the phylogenetic signal of these characters has been only once tested in the systematics of Protoschizomidae. However, our understanding of the pseudosegmentation of the flagellum, along with different terminologies of the relative position of certain setae, creates conflict in terms of homology assessments. In the present contribution, homology hypotheses and the phylogenetic importance of these characters across the only two extant families Protoschizomidae and Hubbardiidae were established and tested. The analyses were based on 44 morphological characters of 22 schizomid exemplar species, and two thelyphonid species as outgroup. Parsimony, Bayesian inference analyses, and the ancestral state reconstruction of the "annuli" characters were conducted. The resulting topology revealed Hubbardiidae as monophyletic with the two subfamilies currently recognized (Hubbardiinae + Megaschizominae). However, Protoschizomidae was not recovered as monophyletic. The ancestral state reconstruction of the number of annuli in the common ancestor of Schizomida suggested gain and loss of the different annuli at different hierarchical levels. Finally, the flagellum contains robust taxonomic characters, but caution needs to be taken when used to diagnose genera.



## 1. Introduction

Body segmentation or metamerism is considered as repetition of a unit comprising characters that involve the whole body along the anterior-posterior axis (Willmer, 1990; Davis and Patel, 1999). Arthropod segmentation and tagmosis still represent a dogma in multiple discussions in a wide range of contexts such as EvoDevo, phylogeny and taxonomy (Fusco and Minelli, 2013). Accordingly to Minelli and Fusco, (2004) tagmosis in arthropods can be invariable in the number of segments of the body (e.g. decapod crustaceans) or variable (e.g. spirostrepid millipedes). In arthropod appendages the tagmosis is evident in antennae or legs, suggesting the metamerism has evolved multiple times in many contexts (Davis and Patel, 1999).

Within Arachnida, tagmosis is evident in the body, like the tergites in the opisthosoma, with subsequent losses in most of the spiders (apomorphic condition), except in Mesothelae which conserves the plesiomorphic condition (Garrison et al., 2016); and appendages, like tarsomeres of legs in Amblypygi and Opiliones (Harvey, 2003; Shultz and Pinto-da-Rocha, 2007), or in the flagellum in Thelyphonida and Palpigradi (Harvey, 2003; Giribet et al., 2014).

One of the most important characters supporting the Uropygi clade (Thelyphonida + Schizomida) is the presence of a distinctive flagellum (post anal appendage). Particularly in schizomids, the female flagellum (Fig. 1) bears different and important taxonomic characters such as "segments" (Fig. 2), and distinctive setal patterns (e.g., Harvey, 1992a; Cokendolpher and Reddell, 1992; Moreno-Gonzaílez et al., 2014; Monjaraz-Ruedas and Francke, 2015).

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**Fig. 1.** Habitus of *Agastoschizomus lucifer* (♀); arrow showing flagellum.

The current terminology of the setae on the flagellum in Schizomida is conflictive in terms of homology statements for phylogenetic analyses, due to the confusion of the relative position of certain setae with respect to each other in the two extant families: Protoschizomidae and Hubbardiidae. Both families were recovered as monophyletic in previous works (i.e. Cokendolpher and Reddell, 1992). The main reason for this confusion is the lack of understanding of the underlying pseudosegmentation in the flagellum. Furthermore, the terminology proposed by Cokendolpher and Reddell (1992) is unsatisfactory. In the present contribution, considering that both families (Hubbardiidae and Protoschizomidae) were recovered monophyletic in the previously mentioned work, we conducted a phylogenetic analysis using a taxon sampling, which represents the diversity of the order Schizomida. Our analyses are based on twenty two schizomid species and two thelyphonid species as outgroup, and 44 morphological characters, to establish homology hypotheses and test the phylogenetic signal of the setal patterns and annuli in female's flagellum across both schizomid families.

## 2. Methods

### 2.1. Taxa

Material examined (Supplementary file 1) is deposited in the following collections: American Museum of Natural History, New York (AMNH); Colección Nacional de Aracnidos, Instituto de Biología, Universidad Nacional Autónoma de México, Mexico City (CNAN); and Natural History Museum, London (NHM).

Observations were made using a Nikon SMZ-800 and a SMZ-1500 stereomicroscope, and a Nikon Eclipse E100 microscope. Terminology follows Cokendolpher and Reddell (1992), except for cheliceral (Lawrence, 1969), and flagellum setae terminology (see below).

Drawings were obtained from digital images taken under visible light with a Nikon Coolpix S10 VR camera attached to a Nikon SMZ-800. Images were edited with Adobe Photoshop CS6, and drawings were edited with Adobe Illustrator CS6.

SEM photographs for four species of the two schizomids families (*Agastoschizomus lucifer*, *Hubbardia pentapeltis*, *Stenochrus portoricensis* and *Mayazomus aluxe*); and two thelyphonid species

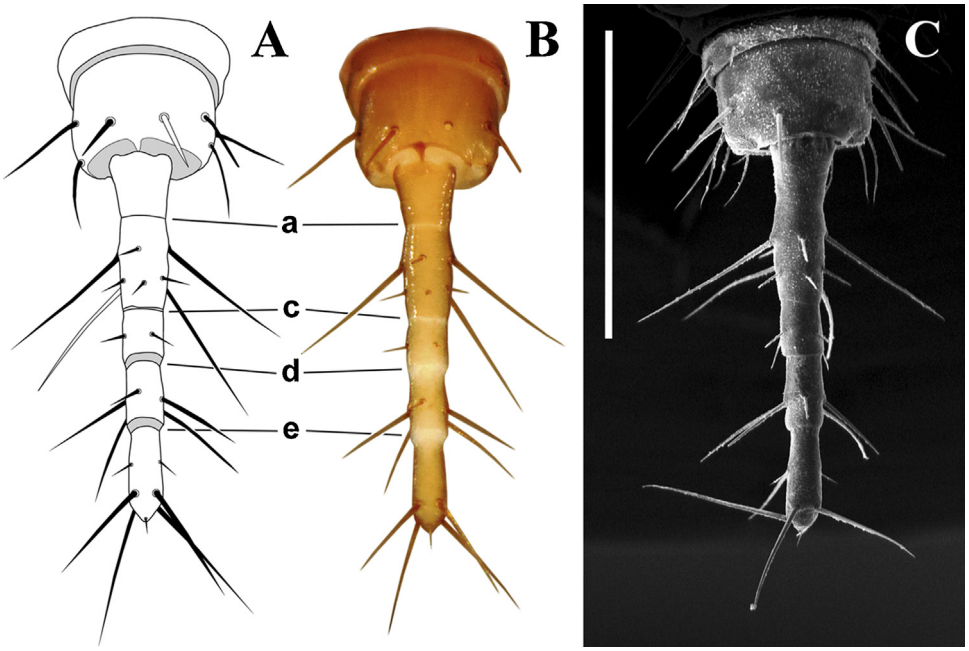


**Fig. 2.** *Agastoschizomus lucifer*. Showing the annuli of the female flagellum under different types of microscope. (A) Schema of the dorsal view, (B) photo of dorsal view under stereoscopic microscope. (C) SEM photograph of dorsal view.