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Taxonomic key to adult females of the scale insect species (Hemiptera: Coccomorpha) associated with coffee roots in Colombia

Alejandro Caballero[1*] and Takumasa Kondo[2]

[1] *Ludwing Maximilian Universität, Munich, Bayern, 81737, Germany*
[2] *Corporación Colombiana de Investigación Agropecuaria - AGROSAVIA, Centro de Investigación Palmira, 763531, Colombia*
* Corresponding author, E-mail: lacaballeror@unal.edu.co

Abstract

A morphology-based illustrated taxonomic key is presented for the identification of the adult females of 59 scale insects that have been recorded associated with coffee roots in Colombia. Previously published doubtful records of species of Diaspididae, Pseudococcidae, and Rhizoecidae were reevaluated and a revised list of scale insects that can be found on coffee roots is presented. A discussion of the morphological variation of *Dysmicoccus neobrevipes* Beardsley, 1959, *Dysmicoccus texensis* (Tinsley, 1900) and *Dysmicoccus joannesiae* (Costa Lima, 1939) is included. The species *Distichlicoccus takumasae* is emended to *Distichlicoccus takumasai*.

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Introduction

Scale insects (Hemiptera: Coccomorpha) with hypogeic habits are considered of high phytosanitary relevance for coffee crops (Rubiaceae: *Coffea* spp.) in Colombia[1]. A total of 65 species of scale insects associated with coffee roots have been recorded in Colombia[2−4]. The most species-rich family is the Pseudococcidae with 28 species distributed in nine genera: *Dysmicoccus* Ferris, 1950 (13 spp.), followed by *Pseudococcus* Westwood, 1840 (four spp.), *Phenacoccus* Cockerell, 1893 (three spp.), *Planococcus* Ferris, 1950, and *Spilococcus* Ferris, 1950 (two spp. each), and *Chorizococcus* McKenzie, 1960, *Distichlicoccus* Ferris, 1950, *Ferrisia* Fullaway, 1923, and *Paraputo* Laing, 1929 (one sp. each). For the family Rhizoecidae, 19 species have been recorded in six genera, namely, *Rhizoecus* Kunckel d'Herculais, 1878 (13 spp.), *Pseudorhizoecus* Green, 1933 (two spp.), and *Capitisetella* Hambleton, 1977, *Coccidella* Hambleton, 1946, *Geococcus* Green, 1902, and *Ripersiella* Tinsley, 1899 (one sp. each). Other minor families include Coccidae and Ortheziidae (five spp. in each family), Xenococcidae (three spp.), and Putoidae and Diaspididae (two spp. in each family) and Margarodidae (one sp.). For this study all previous records were reanalysed with the purpose of providing an accurate list of species

The taxonomic identification of scale insects by a morphological approach is particularly difficult, mainly for two reasons. First, they are small insects (usually < 5 mm) that require the preparation of slide-mounted specimens. Second, the taxonomic keys needed for morphological identifications are primarily designed for adult female specimens[5]. Differing from other insect orders (e.g., Coleoptera, Diptera and Hymenoptera), female scale insects lack well-defined tagmata, as well as sclerites, sutures, or discernible areas. Characters of taxonomic value in scale insects include cuticular processes, such as pores, ducts and, setae[5]. Recognizing these cuticular structures on such small bodies poses a difficult task for non-expert entomologists. To facilitate accessible identification, this manuscript offers an illustrated taxonomic key to scale insect species associated with coffee roots in Colombia and is aimed at users with basic knowledge of scale insect morphology.

Materials and methods

A careful revision of the specimens studied by Caballero et al.[2], preserved in the Scale Insect Collection at the Entomological Museum 'Universidad Nacional Agronomía Bogota' UNAB (Bogotá, Colombia), was carried out to exclude species that are doubtfully recorded from coffee roots in Colombia. This reassessment allowed the compilation of an accurate list of species that could be included in the taxonomic key. Additional species and information from Caballero[3] and Caballero et al.[4] also were used for construction of the key. List of species recorded for Colombia and c ollection data of specimens analized are in Supplemmental Table S1 and S2 respectivately.

The illustrated taxonomic key (Table 1) is based on the external morphology of the adult female with a dichotomous structure. Each couplet after the first one is numbered followed by the number of the preceding couplet in parenthesis, e.g. 12(7) means that couplet 12 is derived from couplet 7; the numbers at the end of the couplet indicate the next couplet in order to arrive at the species name that best matches the character states selected by the user. It is illustrated in most of the steps using microphotographs. Acquisition and analysis of images were done with a Lumenera 1-5C camera and the software Image Pro Insight 8.0. Designs were performed with Affinity Photo V 2.1 and Affinity Designer V 2.1 software. The taxonomic keys were structured with some adaptations of published taxonomic keys[6−15]. The general morphological terminology follows Kondo & Watson[5] with specific terminology for Coccidae[6,16], Margarodidae[17], Ortheziidae[7], Diaspididae[18], Pseudococcidae, Putoidae[8,9], and Rhizoecidae[10,11]. The abdominal segmentation is given as SabdI for abdominal segment 1 to SabdVIII for abdominal segment 8. All microphotographs are of adult female scale insects or their taxonomically important morphological structures.

Results

The following illustrated taxonomic key (Table 1) is a tool for the identification of adult female scale insects (Hemiptera : Sternorrhyncha : Coccomorpha) associated with coffee roots in Colombia, which includes 59 species from seven families (see Supplemental Table S1).

Discussion

The taxonomic key includes 59 species associated with coffee roots. *Hemiberlesia* sp., *Odonaspis* sp., *Rhizoecus stangei* McKenzie, 1962, *Spilococcus mamillariae* (Bouche, 1844), *Planococcus citri* (Risso, 1813) and *Planococcus minor* (Maskell, 1897) were excluded from the key. In the case of the two armoured scale insects, the specimens were found in Berlese funnel samples associated with coffee roots[2], however, there is no evidence of these species feeding on the roots and there are no previous records of association of *Hemiberlesia* nor *Odonaspis* species with coffee roots.

Previous records of single specimens of *R. stangei* and *S. mamillariae* by Caballero et al.[2] were determined as misidentifications of *Rhizoecus caladii* Green, 1933 and *Spilococcus pressus* Ferris, 1950, respectively. *Spilococcus mamillariae* is considered as an oligophagous species, but mainly associated with Cactaceae plants and feeding on the aerial parts of plants[19,20]. There are no records of *S. mamillariae* being found on any plant species of the family Rubiaceae, and hence we have removed this species from the list of species associated with coffee roots.

Table 1. Illustrated taxonomic key.

No.	Details	Ref.
1	Abdominal spiracles present (Fig. 1a)	2
–	Abdominal spiracles absent (Fig. 1b)	7

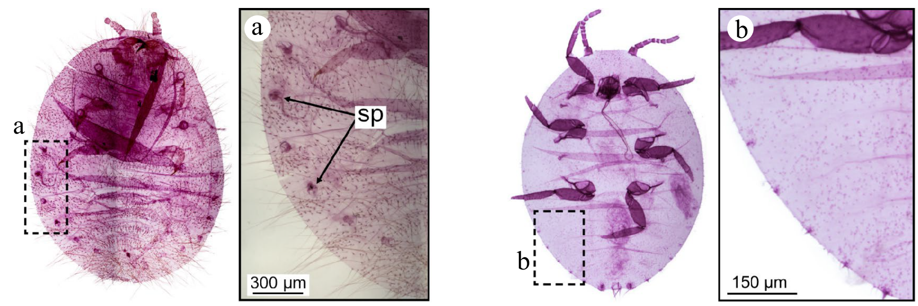

Fig. 1 Abdominal spiracles (sp) on margin (a) present on *Eurhizococcus colombianus*, (b) absent on *Distichlicoccus takumasai*.

No.	Details	Ref.
2(1)	Anal aperture without pores and setae (Fig. 2a); legs shorter than half of the transversal diameter of body (Fig. 2b); eyespots and mouthparts absent	*Eurhizococcus colombianus* Jakubski, 1965
–	Anal aperture forming a well-developed anal ring with pores and setae (Fig. 2c); legs longer than transversal diameter of body; eyespots and mouthparts present (Fig. 2d)	3

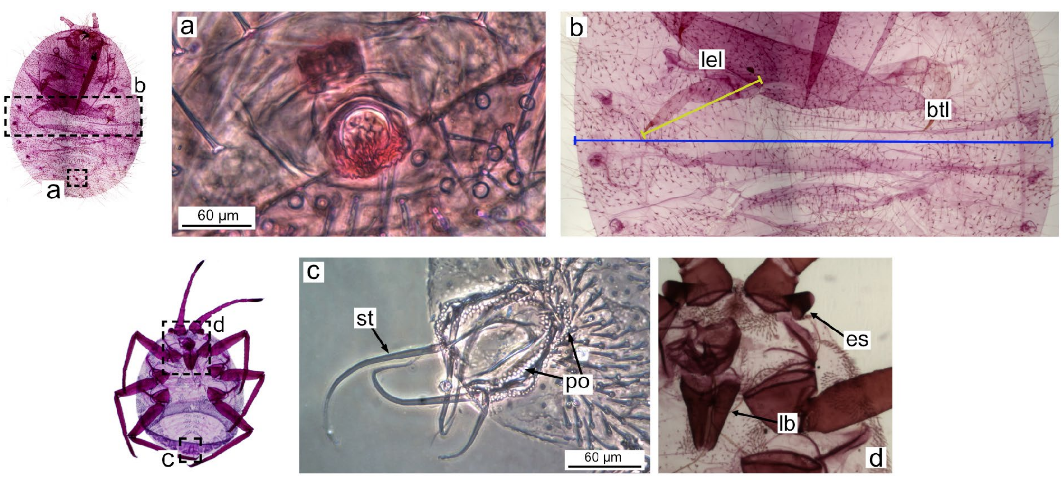

Fig. 2 *Eurhizococcus colombianus*: (a) Anal aperture without pores and setae in the border, (b) section of mid body showing the length of hind leg (lel) and transversal body line (btl). *Insignorthezia insignis*: (c) Anal aperture with pores (po) and setae (st), (d) section of head with protruding eyespot (es) and labium (lb).

(to be continued)

Table 1. (continued)

No.	Details	Ref.
3(2)	Antennae each with eight segments (Fig. 3a)	4
–	Antennae each with fewer than five segments (Fig. 3b)	5

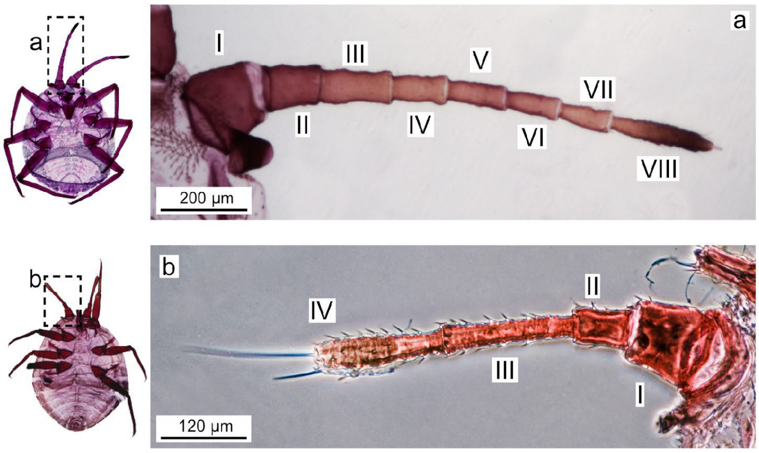

Fig. 3 (a) Eight-segmented antenna. (b) Four-segmented antenna.

No.	Details	Ref.
4(3)	Transversal bands of spines absent in ventral region surrounded by an ovisac band (Fig. 4a); dorsal interantennal area without sclerosis (Fig. 4b)	*Insignorthezia insignis* (Browne, 1887)
–	Transversal bands of spine plates present in ventral region surrounded by an ovisac band (Fig. 4c); longitudinal sclerosis on dorsum in interantennal area (Fig. 4d)	*Praelongorthezia praelonga* (Douglas, 1891)

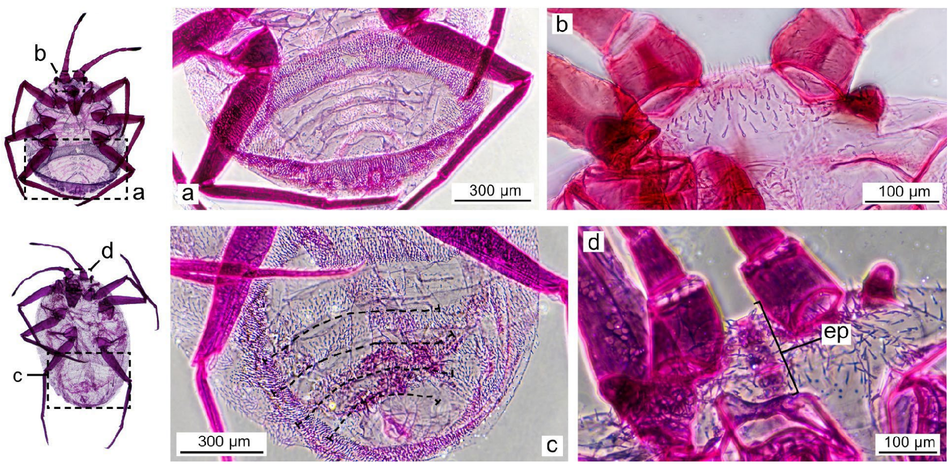

Fig. 4 *Insignorthezia insignis*: (a) Abdomen without transversal clusters of wax plates, (b) Dorsal interantennal area without sclerosis. *Praelongorthezia praelonga*: (c) Abdomen with transversal clusters of wax plates marked by dash lines, (d) dorsal interantennal area with a longitudinal sclerotic plate (ep).

No.	Details	Ref.
5(3)	Antennae each with three segments (Fig. 5a)	*Newsteadia andreae* Caballero, 2021
–	Antennae each with four segments (Fig. 5b)	6

Fig. 5 (a) Three-segmented antenna of *Newsteadia andreae*. Note the presence of pseudosegmentation which gives the appearance of additional segments in the last antennal segment. (b) Four-segmented antenna of *Mixorthezia minima*.

(to be continued)

Table 1. (continued)

No.	Details	Ref.
6(5)	Dorsal area anterior to anal ring with simple pores on protuberances (Fig. 6a); ventral areas surrounding each coxa with a row of wax plate spines (Fig. 6b)	*Mixorthezia minima* Koczné Benedicty & Kozár, 2004
–	Dorsal area anterior to anal ring without simple pores or protuberances (Fig. 6c); ventral areas posterior to each coxa without wax plate spines (Fig. 6d)	*Mixorthezia neotropicalis* (Silvestri, 1924)

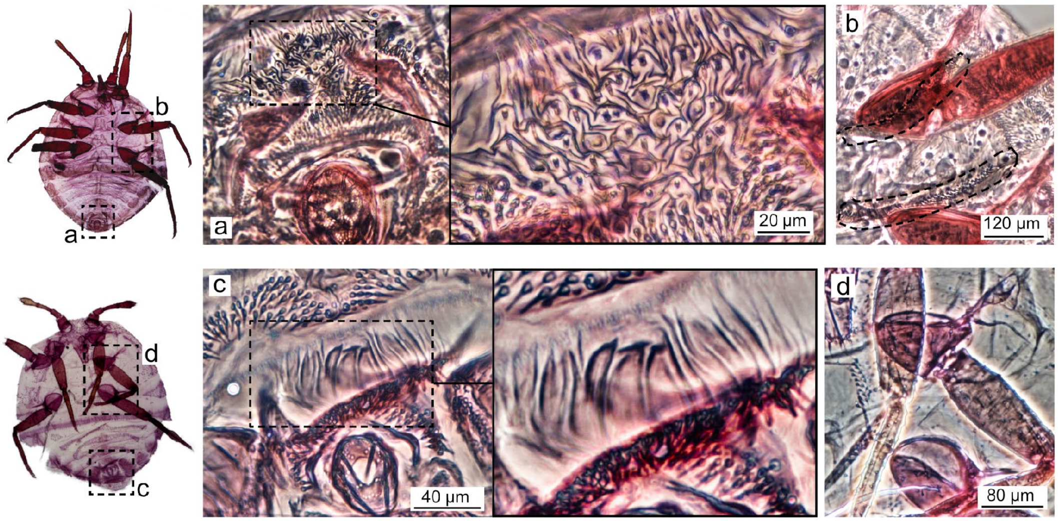

Fig. 6 *Mixorthezia minima*: (a) Dorsum of area anterior to anal ring with close-up of simple pores on protuberances (dash box); (b) ventral area posterior to each coxa with a row of wax plate spines (dash box). *Mixorthezia neotropicalis*: (c) Close-up of dorsum of area anterior to anal ring lacking simple pores on protuberances (dash box); (d) ventral area posterior to each coxa without associated wax plate spines.

No.	Details	Ref.
7(1)	Anal plates present (Fig. 7a)	8
–	Anal plates absent (Fig. 7b)	12

Fig. 7 (a) Anal apparatus of *Saissetia coffeae* with anal plates (ap) covering the anal aperture (aa). (b) Anal apparatus of *Pseudococcus* sp. with anal aperture lacking anal plates.

No.	Details	Ref.
8(7)	Antennae and legs with length similar to or shorter than spiracles (Fig. 8a)	9
–	Antennae and legs with length at least twice as long as spiracles (Fig. 8b)	11

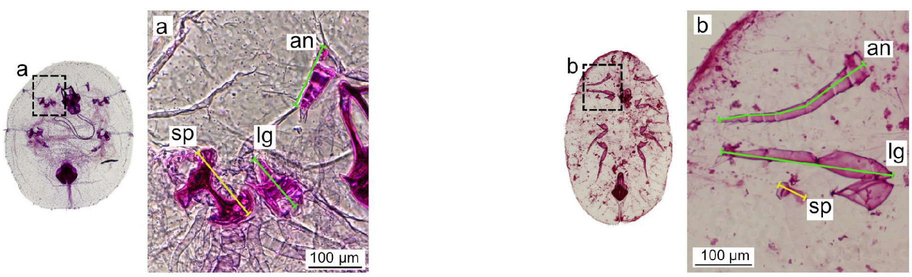

Fig. 8 (a) Antenna (an) and foreleg (lg) (green lines), and anterior spiracle (sp) (yellow line) of *Toumeyella coffeae* showing their relative length. Note the similar size of the limbs and spiracle. (b) Antenna (an) and leg (lg) (green lines), and anterior spiracle (sp) (yellow line) of *Coccus viridis* showing their relative length. Note the relatively smaller size of the spiracle.

(to be continued)

Table 1. (continued)

No.	Details	Ref.
9(8)	Ventral tubular macroducts present (Fig. 9)	*Toumeyella coffeae* Kondo, 2013
–	Ventral tubular macroducts absent	10

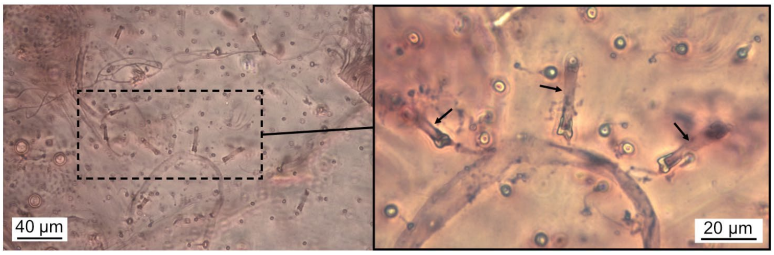

Fig. 9 Ventral tubular macroducts (dash box) and close-up of macroducts (photo on right side).

No.	Details	Ref.
10(9)	Orbicular pores (Fig. 10a) and cribriform platelets present (Fig. 10b); dorsal setae absent; opercular pores absent	*Cryptostigma urichi* (Cockerell, 1894)
–	Orbicular pores and cribriform platelets absent; dorsal setae present (Fig. 10c); numerous opercular pores present throughout mid areas of dorsum (Fig. 10d)	*Akermes colombiensis* Kondo & Williams, 2004

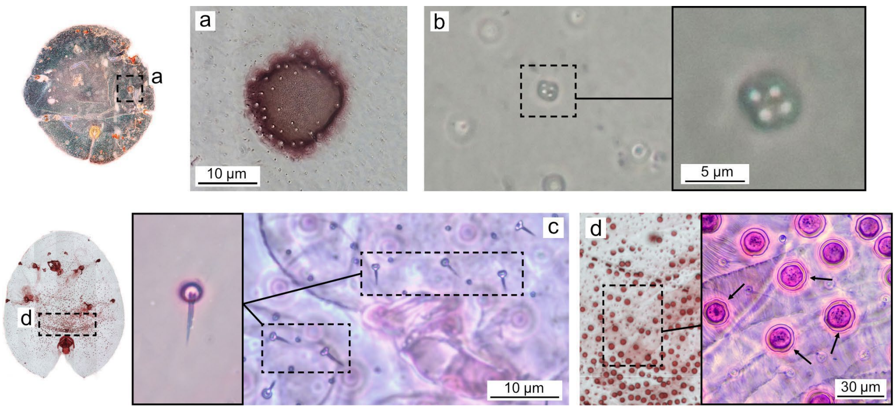

Fig. 10 *Cryptostigma urichi*: (a) Orbicular pore and (b) close-up of a cribriform platelet. *Akermes colombiensis*: (c) Close-up of a dorsal body setae (dash box) and (d) close-up of opercular pores (arrows).

No.	Details	Ref.
11(8)	Band of ventral tubular ducts in lateral and submarginal regions absent, ventral tubular ducts of one type; anal plates without discal setae (Fig. 11a); dorsal body setae capitate or clavate (Fig. 11b); perivulvar pores with seven or eight loculi, rarely with 10 loculi (Fig. 11c)	*Coccus viridis* (Green, 1889)
–	Band of ventral tubular ducts in lateral and submarginal regions present, submarginal region with two types of tubular ducts (Fig. 11d); anal plates with discal setae (Fig. 11e); dorsal body setae spine-like, apically pointed (Fig. 11f); perivulvar pores mostly with 10 loculi (Fig. 11g)	*Saissetia coffeae* (Walker, 1852)

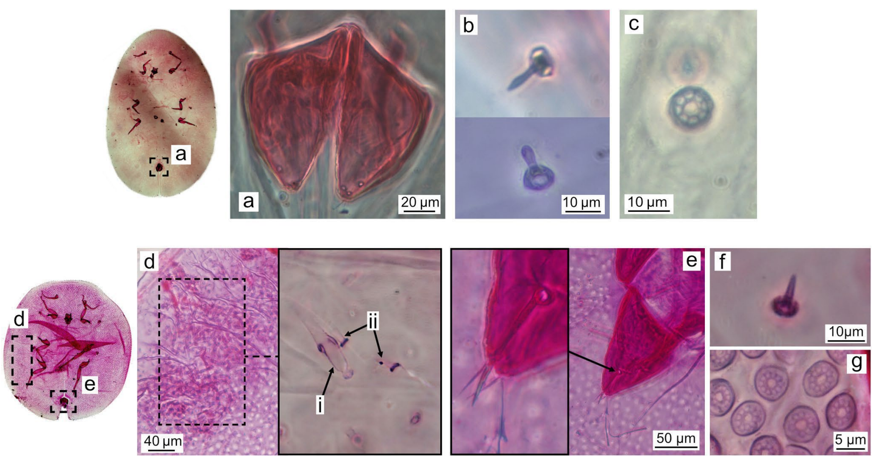

Fig. 11 *Coccus viridis*: (a) Anal plates without discal setae; (b) dorsal body setae capitate (top) or clavate (below); (c) multilocular disc pores mostly with eight loculi. *Saissetia coffeae*: (d) Ventral submarginal region with two types of tubular ducts; (e) each anal plate with a discal seta; (f) dorsal body setae acute; (g) multilocular disc pores with mostly 10 loculi.

(to be continued)

Table 1. (continued)

No.	Details	Ref.
12(7)	Cerarii present on body margin, at least a pair on each anal lobe (Fig. 12a)	13
–	Cerarii absent on body margin (Fig. 12b)	38

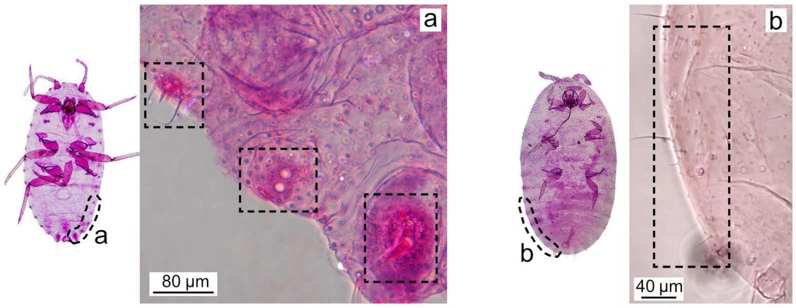

Fig. 12 Abdominal body margin of (a) *Pseudococcus* sp. with three cerarii (dash box) and (b) *Rhizoecus* sp. (dash box) without cerarii.

13(12)	Enlarged oral collar tubular ducts composed of a sclerotized area surrounding the border and a set of flagellated setae (*Ferrisia*-type oral collar tubular ducts) (Fig. 13a)	*Ferrisia uzinuri* Kaydan & Gullan, 2012
–	Oral collar tubular ducts simple, not as above (Fig. 13b) or absent	14

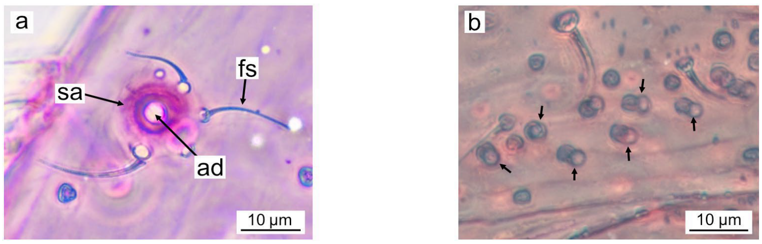

Fig. 13 (a) *Ferrisia*-type oral collar tubular ducts with aperture of tubular duct (ad) surrounded by a sclerotized area (sa) and associated flagellate setae (fs). (b) Oral collar tubular ducts simple (arrows).

14(12)	Antenna with nine segments (Fig. 14a)	15
–	Antenna with eight segments (Fig. 14b) or fewer (Fig. 14c)	19

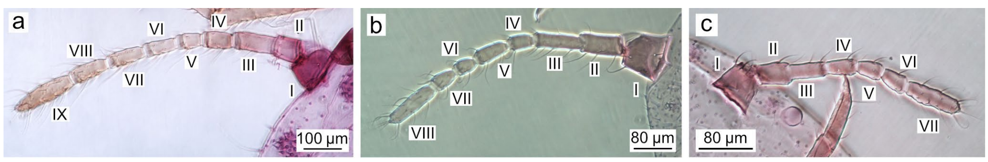

Fig. 14 Antenna with (a) nine segments, (b) eight segments and (c) seven segments.

15(14)	Cerarii with more than five conical setae (Fig. 15a); hind trochanter with six sensilla, three on each surface (Fig. 15b)	16
–	Cerarii with two lanceolate setae (Fig. 15c); hind trochanter with four sensilla, two on each surface (Fig. 15d)	17

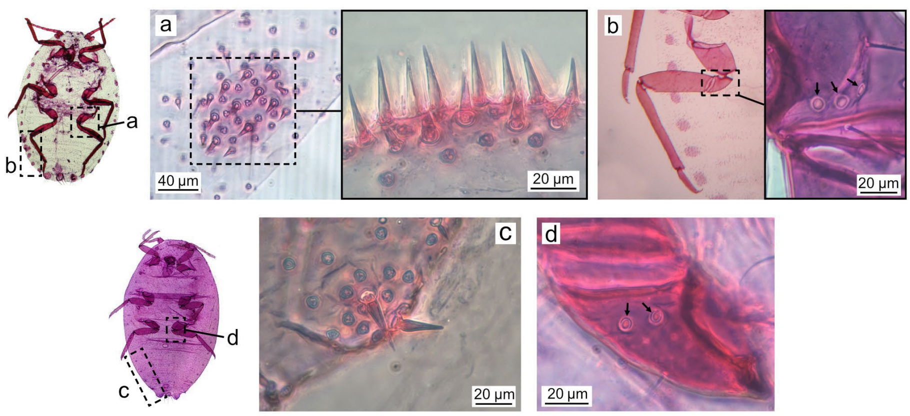

Fig. 15 *Puto barberi*: (a) upper and lateral view of a cerarius, (b) close-up of the surface of trochanter with three sensilla (arrows). *Phenacoccus sisalanus*: (c) cerarius, (d) trochanter with two sensilla (arrows) on single surface.

(to be continued)

Table 1. (continued)

No.	Details	Ref.
16(15)	Cerarii with tubular ducts (Fig. 16a)	*Puto antioquensis* (Murillo, 1931)
–	Cerarii without tubular ducts (Fig. 16b)	*Puto barberi* (Cockerell, 1895)

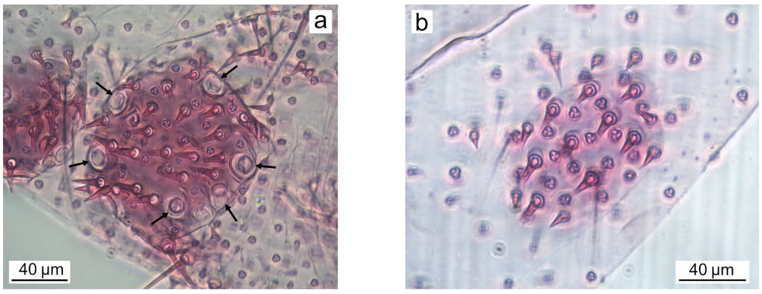

Fig. 16 (a) Cerarius associated with tubular ducts (arrows). (b) Cerarius without tubular ducts.

No.	Details	Ref.
17(15)	Oral collar tubular ducts absent	*Phenacoccus sisalanus* Granara de Willink, 2007
–	Oral collar tubular ducts present, at least on venter (Fig. 17)	18

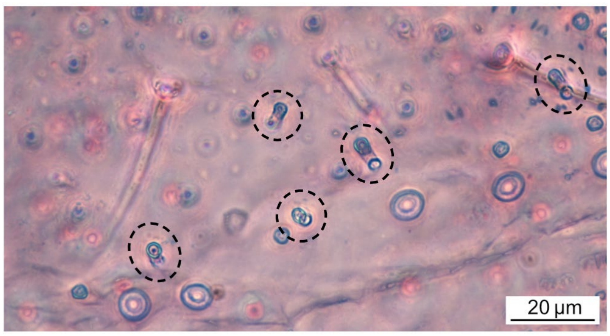

Fig. 17 Ventral surface with oral collar tubular ducts (dash circles).

No.	Details	Ref.
18(17)	Oral collar tubular ducts restricted to venter	*Phenacoccus solani* Ferris, 1918
–	Oral collar tubular ducts present on dorsum and venter	*Phenacoccus parvus* Morrison, 1924
19(14)	Oral rim tubular ducts present (Fig. 18)	20
–	Oral rim tubular ducts absent	26

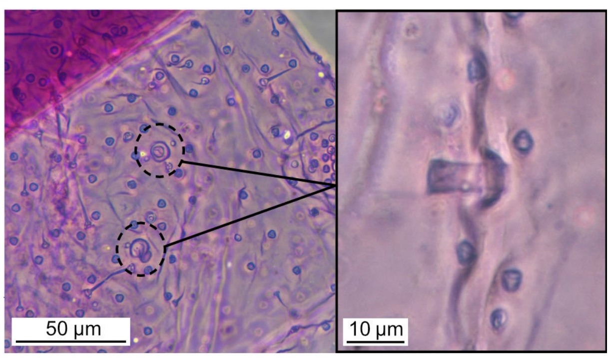

Fig. 18 Oral rim tubular ducts in upper view (dash circles) and close-up of lateral view.

No.	Details	Ref.
20(19)	Oral rim tubular ducts present on venter only	*Pseudococcus landoi* (Balachowsky, 1959)
–	Oral rim tubular ducts present on both dorsum and venter	21
21(20)	Cerarii restricted to anal lobes (Fig. 19a)	*Chorizococcus caribaeus* Williams & Granara de Willink, 1992
–	Cerarii present, at least on the last five abdominal segments (Fig. 19b)	22

(to be continued)

Table 1. (continued)

No.	Details	Ref.

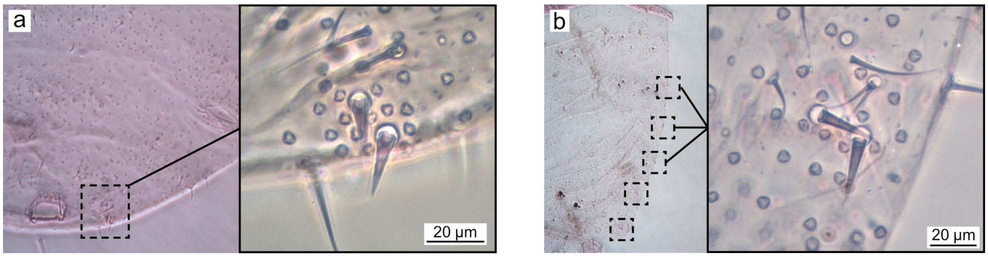

Fig. 19 Location of cerarii (dash boxes) on abdominal margin with close-up of cerarius (a) restricted to anal lobes (dash boxes) and (b) cerarii present on the last five abdominal segments.

No.	Details	Ref.
22(21)	Circulus absent (Fig. 20a)	23
–	Circulus present (Fig. 20b)	24

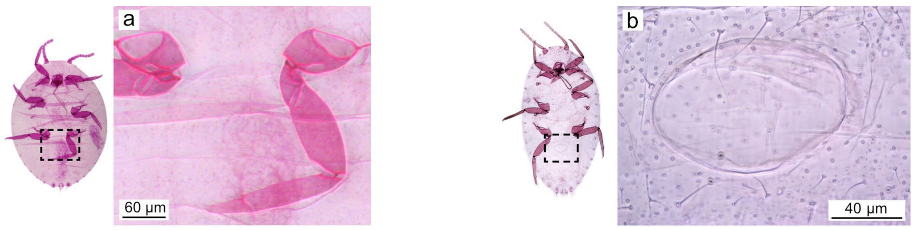

Fig. 20 Ventral mid area of abdominal segments III and IV (dash box) of (a) *Distichlicoccus takumasai* without circulus and (b) *Pseudococcus jackbeardsleyi* with circulus.

No.	Details	Ref.
23(22)	Multilocular disc pores present on venter of SabdIV and posterior segments (Fig. 21a); hind coxa with translucent pores and hind femur without translucent pores (Fig. 21b)	*Spilococcus pressus* Ferris, 1950
–	Multilocular disc pores absent, if some present, not more than three around vulvar opening (i.e. venter of SabdVII or SabdVIII); hind coxa without translucent pores (Fig. 21c) and hind femur with translucent pores (Fig. 21d)	*Distichlicoccus takumasai* Caballero, 2021

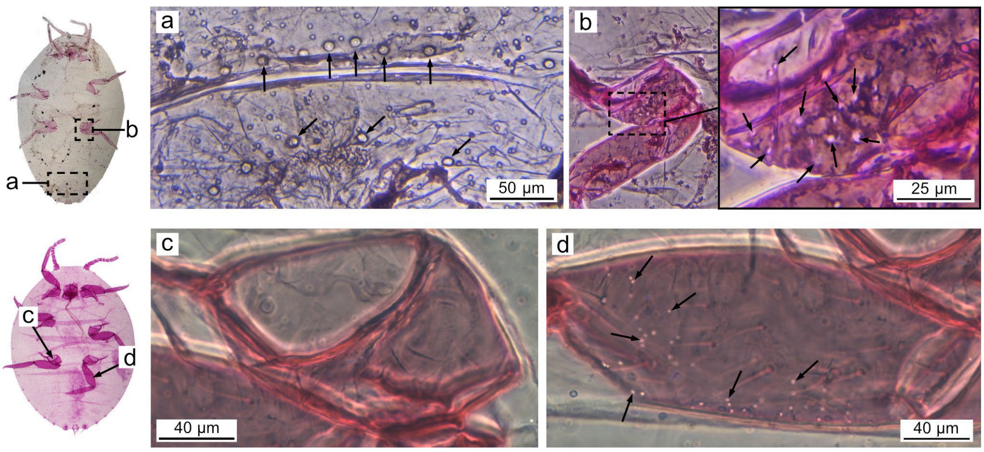

Fig. 21 *Spilococcus pressus*: (a) Ventral section of abdomen with multilocular disc pores (arrows); (b) hind leg with close-up of coxa with translucent pores (arrows). *Distichlicoccus takumasai*: (c) Hind coxa without translucent pores; (d) hind femur with translucent pores (arrows).

No.	Details	Ref.
24(22)	Eyes without discoidal pores nor sclerotized surrounding area (Fig. 22a); circulus with transversal diameter 40 to 60 µm (Fig. 22b)	*Pseudococcus luciae* Caballero, 2021
–	Eyes with discoidal pores and sclerotized surrounding area (Fig. 22c); circulus diameter 100 to 200 µm (Fig. 22d)	26
25(24)	Oral rim tubular ducts on dorsal abdominal segments numbering three to eight; area between posterior ostiole and cerarius of SabdVII without oral rim tubular ducts (Fig. 23a)	*Pseudococcus elisae* Borchsenius, 1947
–	Oral rim tubular ducts on dorsal abdominal segments numbering 14 to 27; area between posterior ostiole and cerarius of SabdVII with an oral rim tubular duct (Fig. 23b)	*Pseudococcus jackbeardsleyi* Gimpel & Miller, 1996

(to be continued)

Table 1. (continued)

No.	Details	Ref.

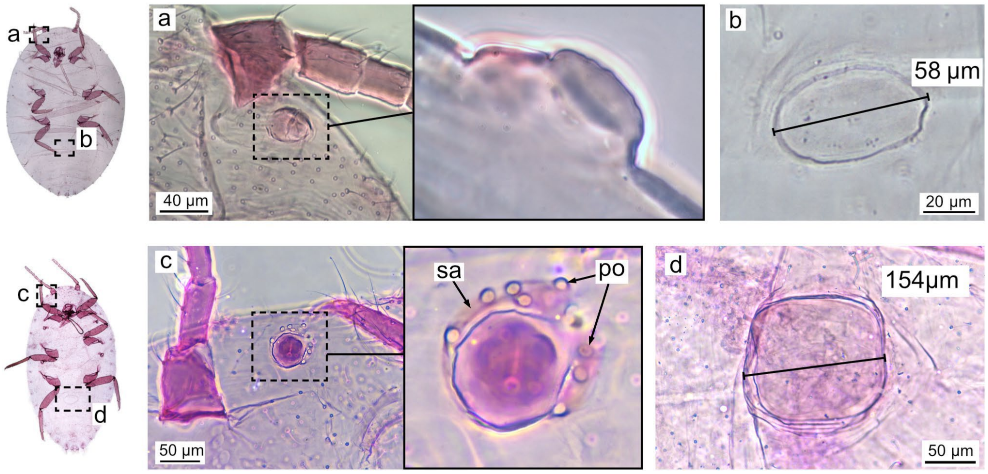

Fig. 22 *Pseudococcus luciae*: (a) Eyespot without surrounding sclerotized area nor associated pores; (b) circulus ca. 58 µm wide. *Pseudococcus jackbeardsleyi*: (a) Eyespot with sclerotized area (sa) and associated pores (po); (d) circulus ca. 154 µm wide.

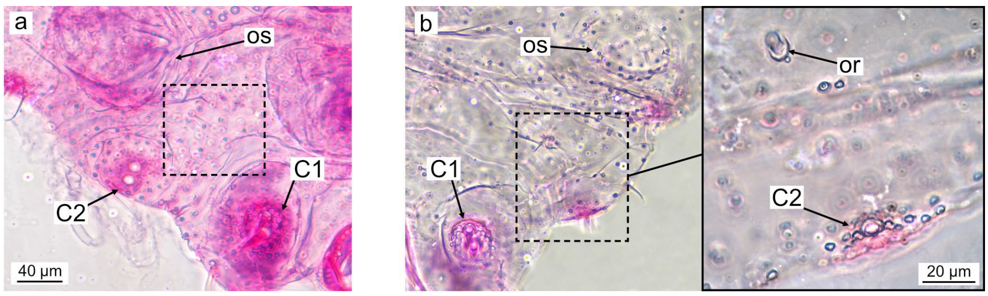

Fig. 23 (a) Dorsal margin of abdominal segments VI to VIII, between cerarius of anal lobe (C1), cerarius of SabdVII (C2) and posterior ostiole (os) without oral rim tubular ducts. (b) Dorsal margin of abdominal segments VI to VIII, between cerarius of anal lobe (C1), cerarius of SabdVII (C2) and posterior ostiole (os) with an oral rim tubular duct and/or cerarius adjacent to SabdVII.

No.	Details	Ref.
26(19)	Oral collar tubular ducts (Fig. 24) on both dorsum and venter	27
–	Oral collar tubular ducts restricted to venter	28

Fig. 24 Oral collar tubular duct in lateral view.

No.	Details	Ref.
27(26)	Hind coxa with translucent pores (Fig. 25a); anal lobe with sclerotized bar, not on a sclerotized area (Fig. 25b); multilocular disc pores present posterior to fore coxa	*Planococcus citri-minor* complex
–	Hind coxa without translucent pores (Fig. 25c); anal lobe without sclerotized bar, on a sclerotized area (Fig. 25d); multilocular disc pores absent posterior to fore coxa	*Dysmicoccus quercicolus* (Ferris, 1918)
28(27)	Oral collar tubular ducts absent on venter of both head and thorax.	29
–	Oral collar tubular ducts present on either head or thorax, but not on both areas (Fig. 26)	30

(to be continued)

Table 1. (continued)

No.	Details	Ref.

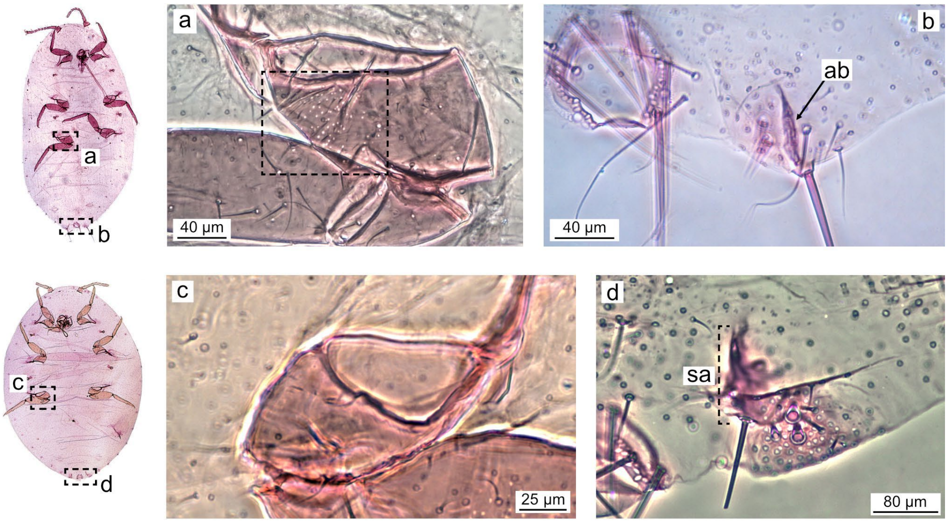

Fig. 25 *Planococcus citri-minor* complex: (a) Hind coxa with translucent pores (dash box) and (b) anal lobe with a sclerotization forming a bar (ab). *Dysmicoccus quercicolus*: (c) Hind coxa without translucent pores and (d) anal lobe with irregular broad sclerotized area (sa).

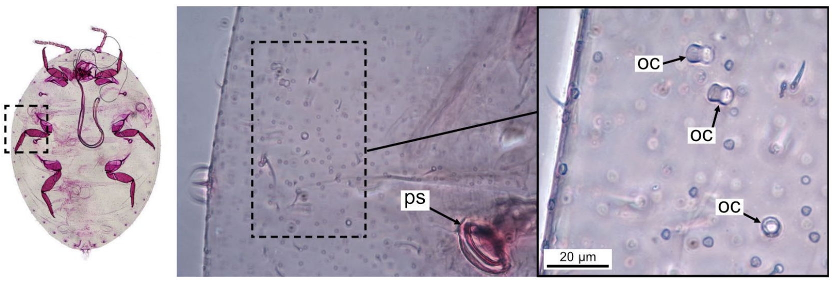

Fig. 26 Marginal area of *Dysmicoccus grassii*, lateral to posterior spiracle (ps), with close-up of oral collar tubular ducts (oc) (left side).

No.	Details	Ref.
29(28)	Translucent pores present on hind coxa, trochanter, femur and tibia (Fig. 27a); marginal clusters of oral collar tubular ducts on venter of SabdVI and SabdVII	*Dysmicoccus caribensis* Granara de Willink, 2009
–	Translucent pores restricted to hind femur and tibia (Fig. 27b); marginal clusters of oral collar tubular ducts present on venter of SabdIV to SabdVII	*Paraputo nasai* Caballero, 2021

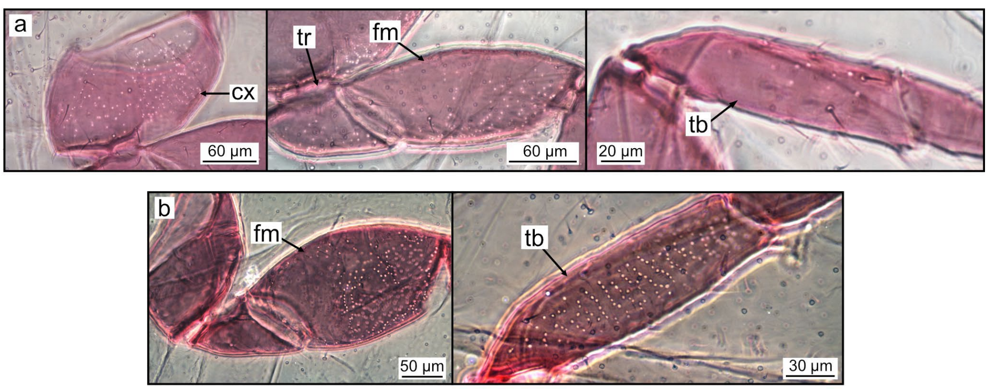

Fig. 27 (a) Hind leg of *Dysmicoccus caribensis* with translucent pores on coxa (cx), trochanter (tr) and femur (fm), and tibia (tb). (b) Hind leg of *Paraputo nasai* with translucent pores restricted to femur (fm) and tibia (tb).

No.	Details	Ref.
30(28)	Hind coxa with translucent pores (Fig. 28a)	*Dysmicoccus sylvarum* Williams & Granara de Willink, 1992
–	Hind coxa without translucent pores (Fig. 28b)	31

(to be continued)

Table 1. (continued)

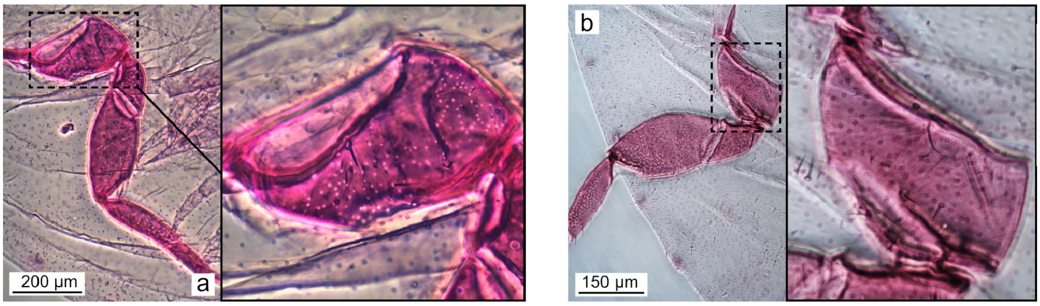

Fig. 28 (a) Translucent pores on hind coxa. (b) Translucent pores absent on hind coxa.

No.	Details	Ref.
31(30)	Hind trochanter with translucent pores (Fig. 29a)	*Dysmicoccus varius* Granara de Willink, 2009
–	Hind trochanter without translucent pores (Fig. 29b)	32

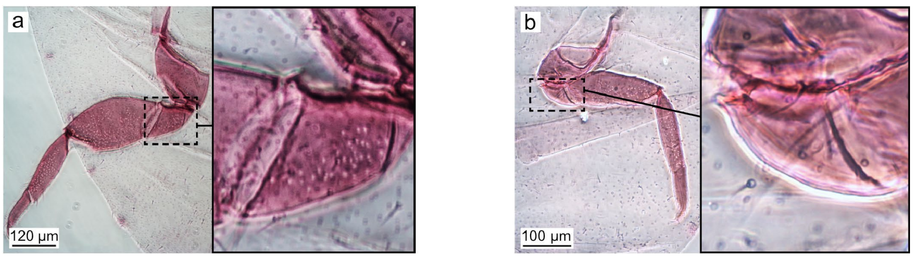

Fig. 29 Translucent pores (a) on hind trochanter, (b) absent from hind trochanter.

No.	Details	Ref.
32(31)	Oral collar tubular ducts present on margin of thorax (Fig. 30)	33
–	Oral collar tubular ducts absent from margin of thorax	34

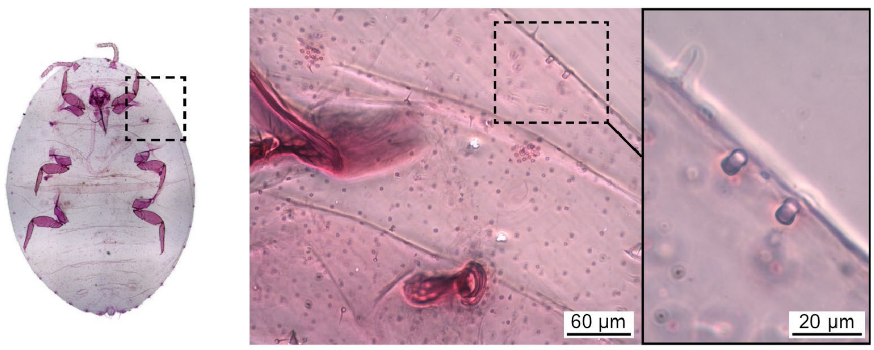

Fig. 30 Prothorax margin of *Dysmicoccus grassii* with close-up of oral collar tubular ducts.

No.	Details	Ref.
33(32)	Multilocular disc pores absent on SabdV; dorsal area immediately anterior to anal ring with tuft of flagellate setae; longest flagellate seta as long as diameter of anal ring (Fig. 31a), and discoidal pores larger than trilocular pores (Fig. 31b)	*Dysmicoccus radicis* (Green, 1933)
–	Multilocular disc pores present on SabdV; dorsal area immediately anterior to anal ring without a tuft of flagellate setae; flagellate setae much shorter than diameter of anal ring (Fig. 31c) and discoidal pores smaller than trilocular pores (Fig. 31d)	*Dysmicoccus grassii* (Leonardi, 1913)
34(32)	Oral collar tubular ducts absent in interantennal area	35
–	Oral collar tubular ducts present in interantennal area (Fig. 32)	36
35(34)	Translucent pores on hind leg restricted to tibia (Fig. 33a)	*Dysmicoccus perotensis* Granara de Willink, 2009
–	Translucent pores on hind leg present on tibia and femur (Fig. 33b)	*Dysmicoccus joannesiae-neobrevipes* complex

(to be continued)

Table 1. (continued)

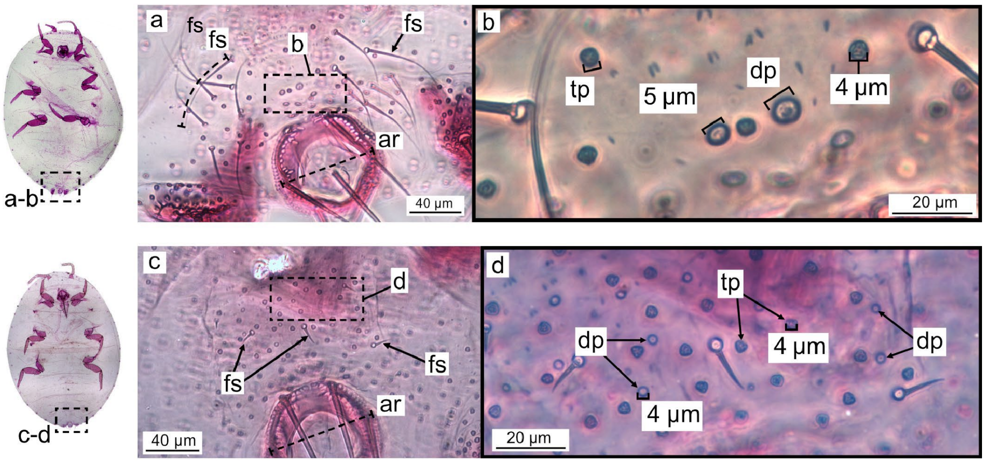

Fig. 31 *Dysmicoccus radicis*: (a) Area anterior to anal ring with a cluster of flagellate setae (fs) and anal ring (ar) showing the diameter of the different pores (dash box); (b) discoidal pores (dp) and trilocular pores (tp). *Dysmicoccus grassii*: (c) Area anterior to anal ring with scattered short flagellate setae (fs) contrasted with anal ring (ar) diameter (dash box); (d) discoidal pores (dp) and trilocular pores (tp) with similar diameter.

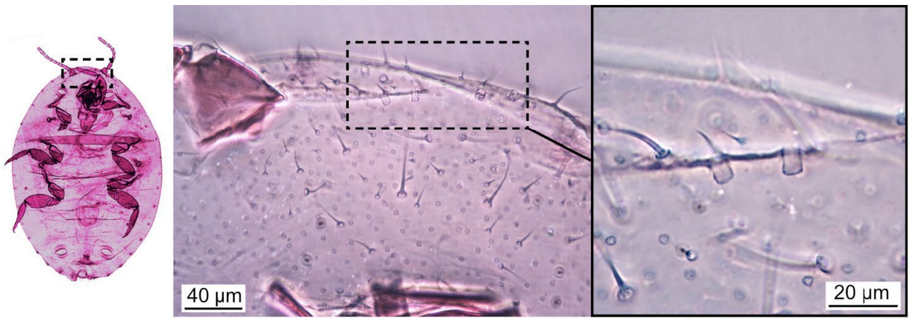

Fig. 32 Interantennal area (dash box) of *Dysmicoccus brevipes* with close-up of oral collar tubular ducts.

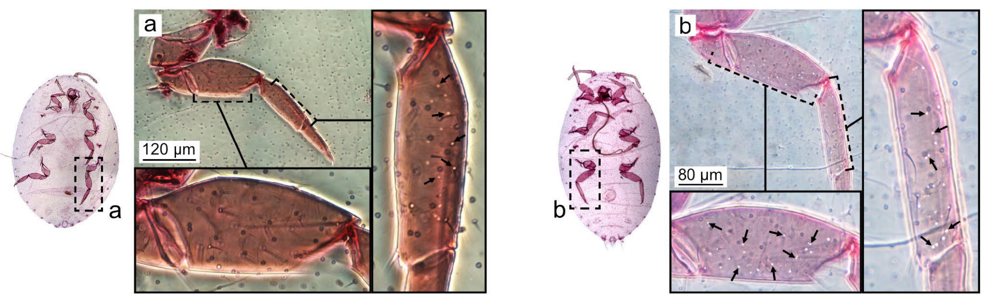

Fig. 33 (a) Hind leg of *Dysmicoccus perotensis* with close-up of femur and tibia with translucent pores on tibia only (arrows). (b) Hind leg of *Dysmicoccus joannesiae-neobrevipes* complex with close-up of femur and tibia with translucent pores (arrows).

No.	Details	Ref.
36(34)	Hind coxa with translucent pores (see Fig. 28a)	*Dysmicoccus mackenziei* Beardsleyi, 1965
–	Hind coxa without translucent pores (see Fig. 28b)	37
37(36)	Dorsal SabdVIII setae forming a tuft-like group, each seta conspicuously longer than remaining dorsal abdominal setae (Fig. 34a) and setal length similar to anal ring diameter (60–80 µm long)	*Dysmicoccus brevipes* (Cockerell, 1893)
–	Dorsal SabdVIII setae evenly distributed, each setae as long as remaining dorsal abdominal setae (Fig. 34b) and length less than half diameter of anal ring	*Dysmicoccus texensis-neobrevipes* complex
38(12)	Tritubular ducts absent	39
–	Tritubular ducts present (Fig. 35a-b)	46

(to be continued)

Table 1. (continued)

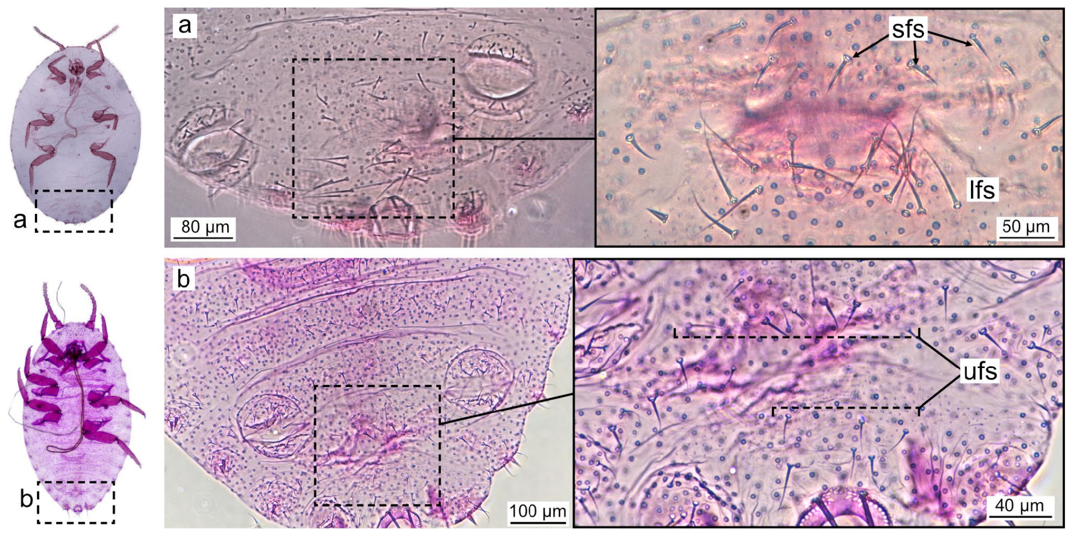

Fig. 34 (a) Abdomen of *Dysmicoccus brevipes* with dorsal setae on SabdVIII (lfs) longer than setae on anterior segments (sfs). (b) Abdomen of *Dysmicoccus texensis-neobrevipes* complex with dorsal setae (ufs) along the abdominal segments of uniform length and scattered distribution.

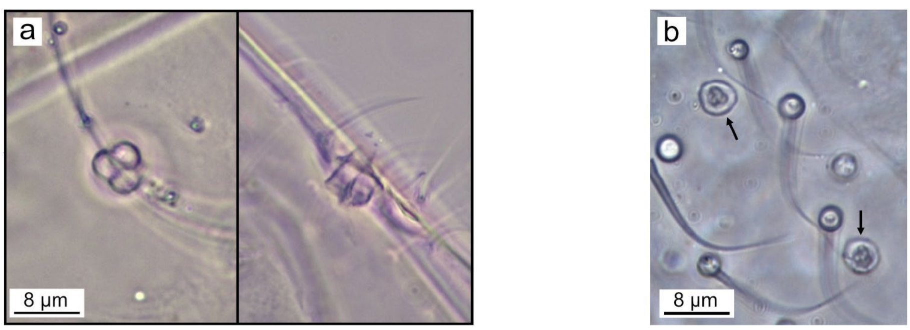

Fig. 35 (a) Tritubular duct in upper (left) and lateral view (right) with the border of the cuticular ring attached to tubules. (b) Tritubular duct with the border of the cuticular ring widely separated from tubules (arrows).

No.	Details	Ref.
39(38)	Anal lobes strongly protruded, bulbiform (Fig. 36a) jutting out from margin for a distance equivalent to diameter of anal ring	40
–	Anal lobes shallow, if protruded, their length never more than half of diameter of anal ring (Fig. 36b)	42

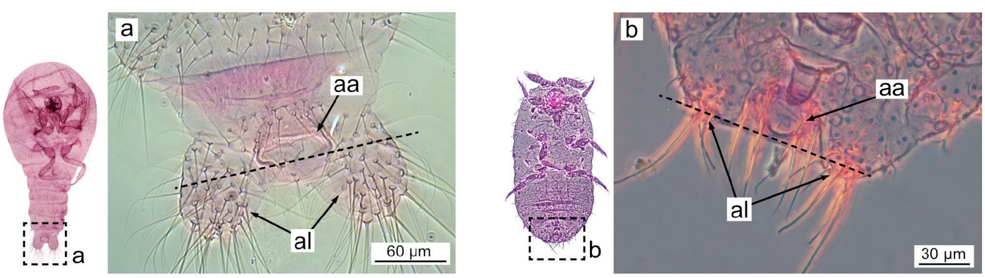

Fig. 36 (a) Abdomen of *Neochavesia caldasiae* with anal lobes (al) protruding beyond the anal aperture (aa). (b) Abdomen of *Ripersiella* sp. with anal lobes (al) at the same level as the anal aperture (aa).

No.	Details	Ref.
40(39)	Anal aperture located at the same level as the base of anal lobes (Fig. 37a); antennae located on ventral margin of head	*Neochavesia caldasiae* (Balachowsky, 1957)
–	Anal aperture located anterior to bases of anal lobes (Fig. 37b); antennae located on dorsum of head	41

(to be continued)

Table 1. (continued)

No.	Details	Ref.

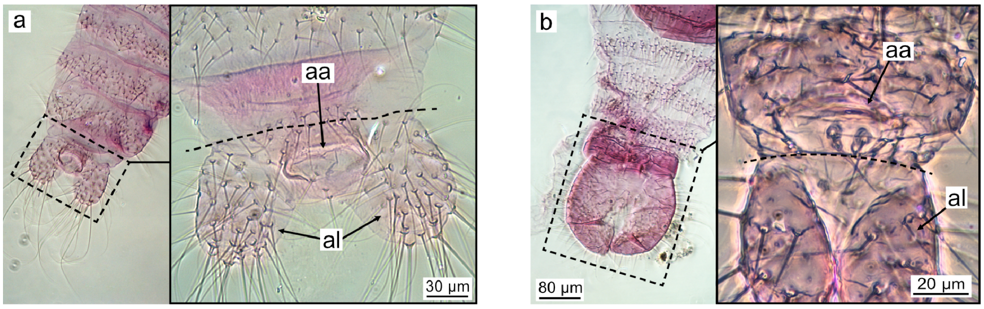

Fig. 37 (a) Abdomen of *Neochavesia caldasiae* with anal aperture (aa) positioned between the anal lobes (al), at the same level as the bases of anal lobes (dash line). (b) Abdomen of *Neochavesia eversi* with anal aperture (aa) situated anterior to the bases of the anal lobes (al) (dash line).

41(40)	Antennae each with five segments, situated on a membranous base (Fig. 38a); length of hind claw less than length of hind tarsus (Fig. 38b)	*Neochavesia trinidadensis* (Beardsley, 1970)
–	Antennae each with four segments, situated on a sclerotized base (Fig. 38c); hind claw longer than hind tarsus (Fig. 38d)	*Neochavesia eversi* (Beardsley, 1970)

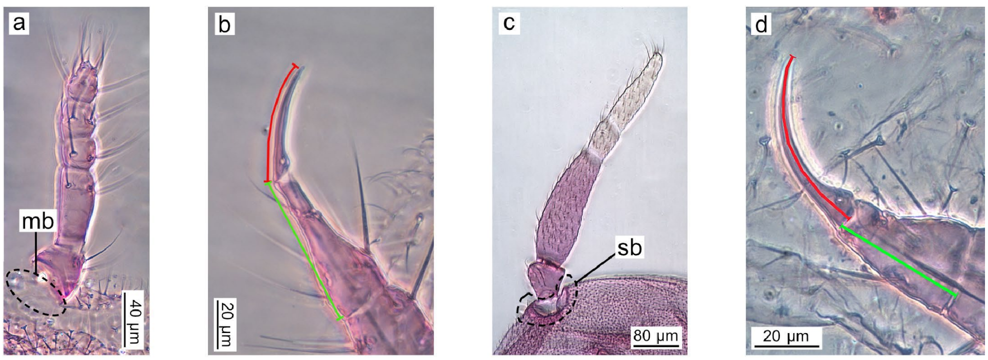

Fig. 38 (a) Antenna with four segments and a membranous base (mb). (b) Hind tarsus (green line) longer than the hind claw (red line). (c) Antenna with four segments and a sclerotized base (sb). (d) Hind tarsus (green line) shorter than hind claw (red line).

42(39)	Body setae capitate, at least on one surface (Fig. 39a)	43
–	Body setae never capitate (Fig. 39b)	44

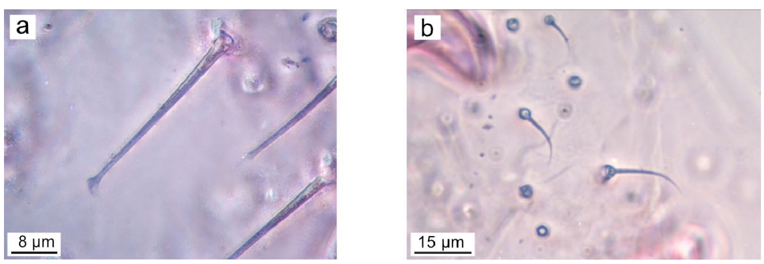

Fig. 39 (a) Capitate setae. (b) Flagellate setae.

43(42)	Anal aperture without associated cells (Fig. 40a); three-segmented antennae (Fig. 40b); ventral setae in median and submedian regions capitate	*Capitisitella migrans* (Green, 1933)
–	Anal aperture surrounded by cells (Fig. 40c); six-segmented antennae (Fig. 40d); ventral setae in medial and submedial regions flagellate	*Williamsrhizoecus coffeae* Caballero & Ramos, 2018
44(42)	Three-segmented antennae (Fig. 41a); circulus present (Fig. 41b)	*Pseudorhizoecus bari* Caballero & Ramos, 2018
–	Five-segmented antennae (Fig. 41c); circulus absent	45

(to be continued)

Table 1. (continued)

No.	Details	Ref.

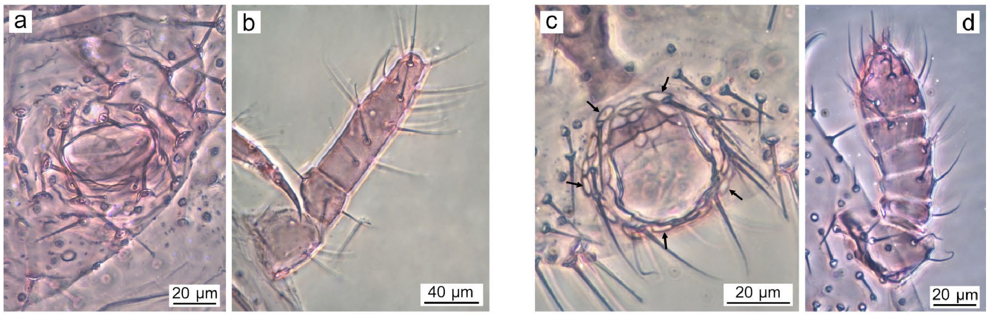

Fig. 40 *Capitisitella migrans*: (a) Anal aperture of surrounded only by setae; (b) antenna composed of three segments. *Williamsrhizoecus coffeae*: (c) Anal aperture of surrounded by setae and cells (flesh); (d) antenna composed of six segments.

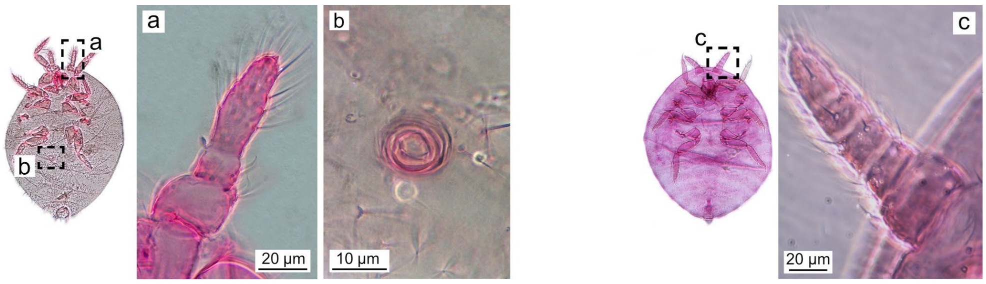

Fig. 41 *Pseudorhizoecus bari*: (a) Antenna composed of three segments and (b) circulus. (c) Antenna of *Pseudorhizoecus proximus* composed of five segments.

No.	Details	Ref.
45(44)	Multilocular disc pores absent; anal aperture ornamented with small protuberances and two to five short setae, each seta never longer than 1/3 diameter of anal aperture, without cells (Fig. 42a)	*Pseudorhizoecus proximus* Green, 1933
–	Multilocular disc pores present (Fig. 42b); anal aperture not ornamented with small protruberances, ring with well-developed cells and six long setae, each seta as long as diameter of anal ring (Fig. 42c)	*Ripersiella andensis* (Hambleton, 1946)

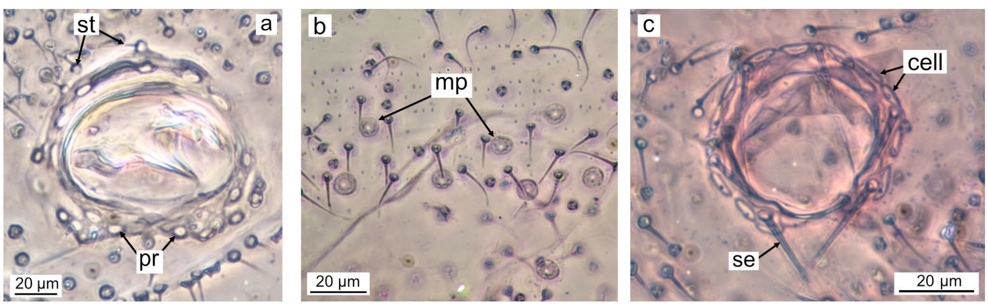

Fig. 42 (a) Anal aperture of *Pseudorhizoecus proximus* surrounded by protuberances (pr) and a few short setae (st). *Ripersiella andensis*: (b) Ventral section of abdomen with multilocular disc pores (mp); (c) anal aperture with a ring of cells and six long setae (se).

No.	Details	Ref.
46(38)	Anal lobes strongly protruded, conical, each one with a stout spine at apex (Fig. 43a)	*Geococcus coffeae* Green, 1933
–	Anal lobes flat or barely protruded, without spines at apex (Fig. 43b)	47
47(46)	Venter of abdomen with clusters of trilocular pores in medial region (Fig. 44a)	*Coccidella ecuadorina* Konczné Benedicty & Foldi, 2004
–	Venter of abdomen with trilocular pores evenly dispersed, never forming clusters in medial region (Fig. 44b)	48

(to be continued)

Table 1. (continued)

No.	Details	Ref.

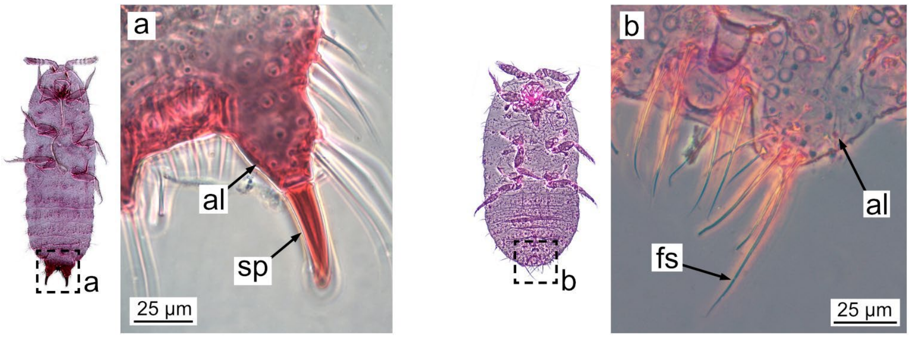

Fig. 43 (a) Abdomen of *Geococcus coffeae* with protruding anal lobe (al) with a stout spine at the apex (sp). (b) Abdomen of *Rhizoecus* sp. with anal lobe (al) flat, with numerous flagellate setae (fs) at the apex.

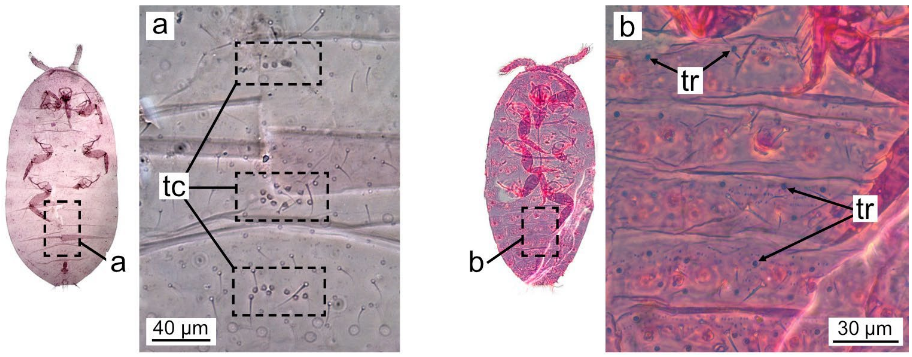

Fig. 44 (a) Ventral surface of *Coccidella ecuadorina* with clusters of trilocular pores (tc) (dash box) on medial region of abdomen. (b) Ventral surface of *Rhizoecus* sp. with trilocular pores (tr) scattered on venter of abdomen.

No.	Details	Ref.
48(47)	Antennae with six well-developed segments (Fig. 45a)	51
–	Antennae with five well-developed segments (Fig. 45b), apical segment sometimes partially divided (Fig. 45c)	49

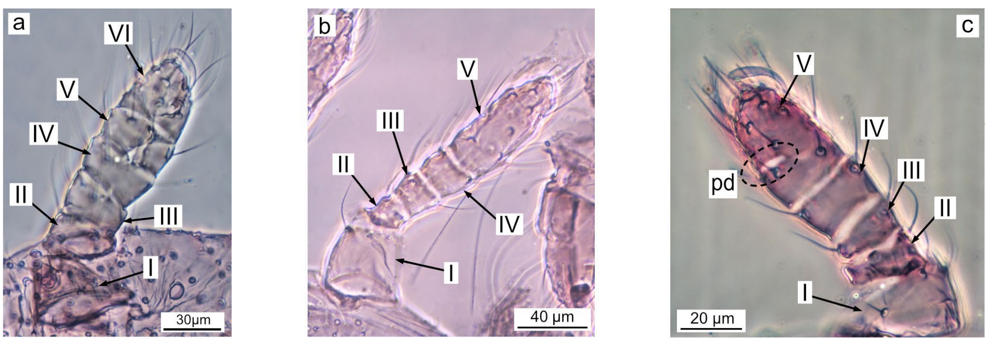

Fig. 45 (a) Six-segmented antenna. (b) Five-segmented antenna. (c) Five-segmented antenna with partially divided apical segment (pd). Note: antennal segments numbered in Roman numerals.

No.	Details	Ref.
49(48)	Antennae length more than 140 µm (Fig. 46a); tritubular ducts of similar diameter to trilocular pores (± 2 µm variation) (Fig. 46b); tritubular ducts with space between ductules and edge as wide as the ductules (Fig. 46c); slender ductule, width/length ratio 1:6	*Rhizoecus coffeae* Laing, 1925
–	Antennae length less than 130 µm (Fig. 46d); tritubular ducts of diameter nearly twice diameter of trilocular pores (Fig. 46e); tritubular ducts with reduced space or without space between ductules and edge (Fig. 46f); stout ductule, width/length ratio 1:3	50
50(49)	Tubular ducts present (Fig. 47a); each anal lobe with around 28 dorsal setae of similar length, greater than 30 µm (Fig. 47b, al); and dorsal marginal clusters of setae on SabdVII 20–30 µm long (Fig. 47b, SabdVII)	*Rhizoecus setosus* (Hambleton, 1946)
–	Tubular ducts absent; each anal lobe with around 14 dorsal setae, with length less than 15 µm (Fig. 47c, al); dorsal marginal clusters of setae on SabdVII with length less 15 µm (Fig. 47c, SabdVII)	*Rhizoecus compotor* Williams & Granara de Willink, 1992

(to be continued)

Table 1. (continued)

No.	Details	Ref.

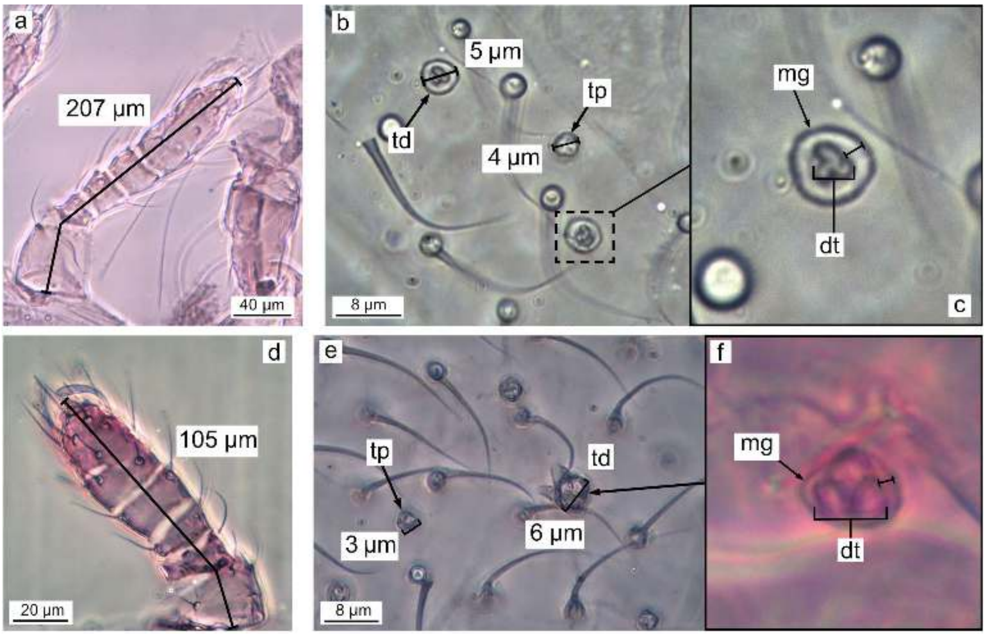

Fig. 46 (a) Antenna ca. 207 µm long. (b) Tritubular ducts (td) and trilocular pores (tp) with similar diameter. (c) Close-up of a tritubular duct indicating the space between the cuticular ring (mg) and the ductule (dt). (d) Antenna ca. 105 µm long. (e) Each tritubular duct (td) twice the diameter of a trilocular pore (tp). (f) Close-up of tritubular duct without a space between the cuticular ring (mg) and the ductule (dt).

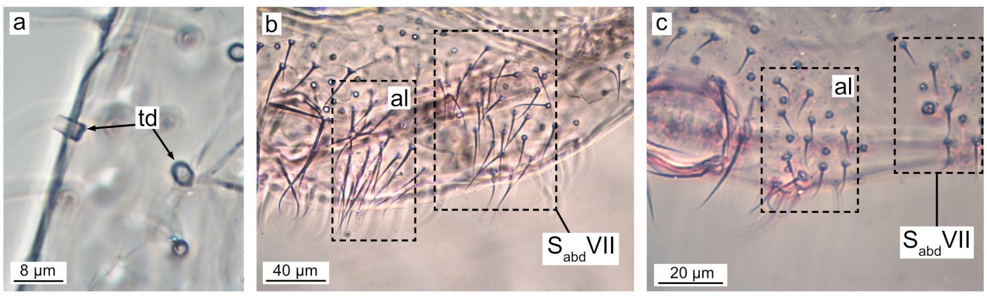

Fig. 47 *Rhizoecus setosus*: (a) Tubular ducts (td); (b) anal lobe (al) and abdominal segment (SabdVII) with marginal clusters of setae longer than 30 µm. (c) Abdomen of *Rhizoecus compotor* with marginal cluster of setae shorter than 20 µm on anal lobe (al) and abdominal segment (SabdVII).

51(48)	Fore tibia with at least one of two internal preapical setae spine-like (Fig. 48a-b)	52
–	Fore tibia with both internal preapical setae flagellate (Fig. 48c)	56

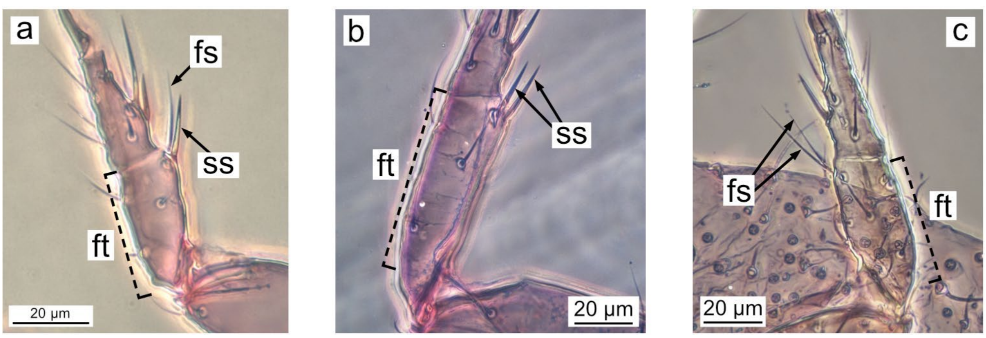

Fig. 48 Fore legs with preapical setae on tibia (ft): (a) one flagellate (fs) and one spine seta (ss), (b) with a pair of spine setae (ss), (c) with a pair of flagellate setae (fs).

(to be continued)

Table 1. (continued)

No.	Details	Ref.
52(51)	Fore tibia with one internal preapical spine-like setae and other seta flagellate (Fig. 48a); anal ring composed of spine-like setae (Fig. 49a); circulus absent	*Rhizoecus spinipes* (Hambleton, 1946)
–	Fore tibia with both internal preapical setae spine-like (Fig. 48b); anal ring composed of flagellate-like setae (Fig. 49b); at least, one circulus present (Fig. 49c)	53

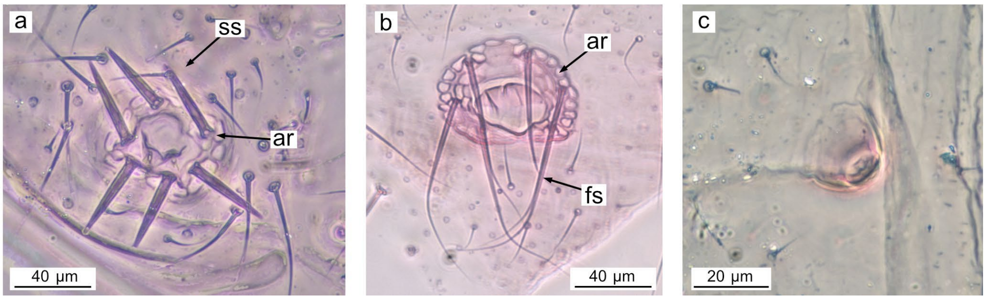

Fig. 49 (a) Anal ring (ar) of *Rhizoecus spinipes* with spine-like setae (ss). (b) Anal ring (ar) of *Rhizoecus arabicus* with flagellate setae (fs). (c) Circulus of *Rhizoecus cacticans*.

No.	Details	Ref.
53(52)	Claw digitules setose and short, length less than half length of claw (Fig. 50a)	54
–	Claw digitules capitate and long, as long as claw (Fig. 50b)	55

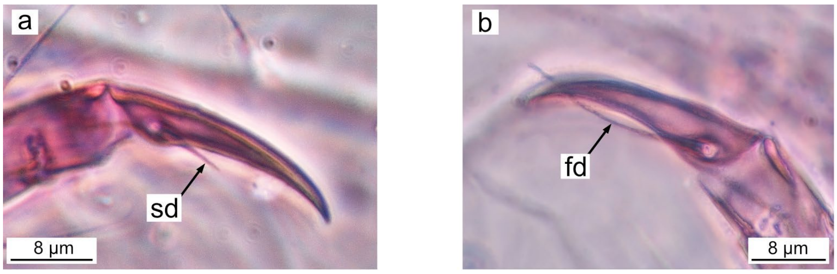

Fig. 50 Claw with claw digitule: (a) setose (sd), (b) flagellate (fd).

No.	Details	Ref.
54(53)	Anal ring with external row composed of 35 cells or more (Fig. 51a, ext); anal ring with external and internal rows separated by a space as wide as a cell of the external row (Fig. 51a, spc); anal ring cells without spicules (Fig. 51a, sp)	*Rhizoecus variabilis* Hambleton, 1978
–	Anal ring with external row composed of less than 30 cells (Fig. 51b, ext); anal ring with external and internal rows separated by a narrow space, as wide as half (or less) a cell of the external row (Fig. 51b, spc); anal ring cells with spicules (Fig. 51b, sp)	*Rhizoecus arabicus* Hambleton, 1976

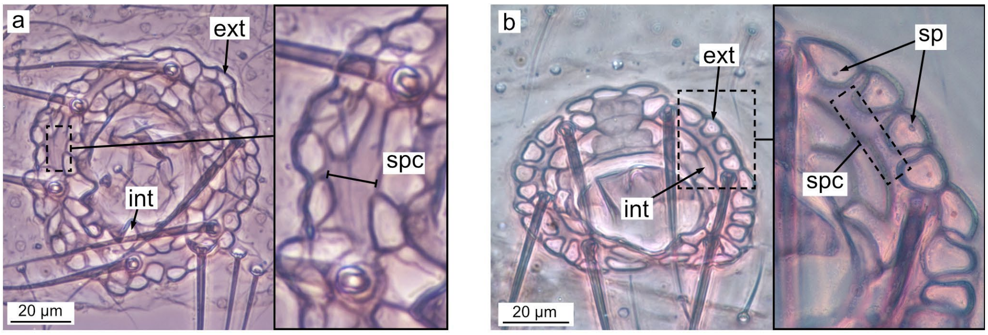

Fig. 51 (a) Anal ring of *Rhizoecus variabilis* with external row (ext) of anal ring consisting of over 35 cells; external row separated from the internal row (int) by a similar width as the diameter of a cell (spc). (b) Anal ring of *Rhizoecus arabicus* with external row (ext) of anal ring with less than 30 cells; external row separated from the internal row (int) by a width less than half the diameter of a cell (spc); cells of the external row with spicules (sp).

No.	Details	Ref.
55(53)	More than 80 tritubular ducts; circulus with basal diameter at least five times greater than apical diameter (Fig. 52a); stick-like genital chamber, parallel borders and all of similar width and structure, length across about two abdominal segments (169–175 µm long) (Fig. 52b)	*Rhizoecus atlanticus* (Hambleton, 1946)
–	Less than 50 tritubular ducts; circulus with basal diameter less than three times the apical diameter (Fig. 52c); genital chamber with basal third two times wider than anterior two-thirds, length across one abdominal segment (43–52 µm long) (Fig. 52d)	*Rhizoecus cacticans* (Hambleton, 1946)

(to be continued)

Table 1. (continued)

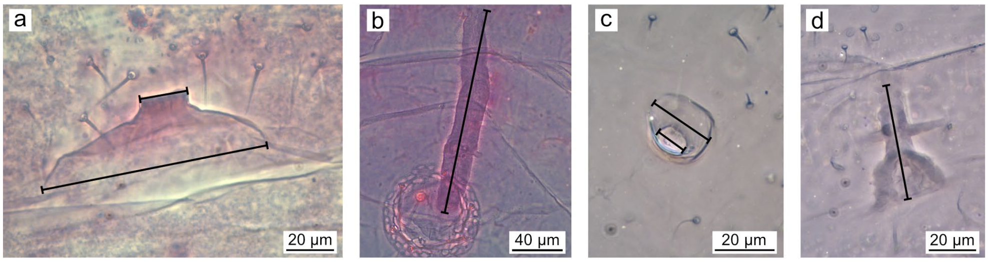

Fig. 52 *Rhizoecus atlanticus*: (a) Circulus with diameter at base five times the apical diameter, (b) genital chamber tubular shape, length ca. 150 µm long. *Rhizoecus cacticans*: (c) Circulus with diameter at base about two times the apical diameter, (d) genital chamber with proximal section basiform and distal section tubular, with arms, length ca. 45 µm long.

No.	Details	Ref.
56(51)	Multilocular disc pores absent on dorsum	*Rhizoecus mayanus* (Hambleton, 1946)
–	Multilocular disc pores present on dorsum	57
57(56)	Marginal prothoracic setae length greater than 50 µm (Fig. 53a); marginal SabdVII setae length greater than 45 µm (Fig 53b)	*Rhizoecus colombiensis* Ramos-Portilla & Caballero, 2016
–	Marginal prothoracic setae length less than 25 µm (Fig. 53c); marginal SabdVII setae length less than 30 µm (Fig. 53d)	58

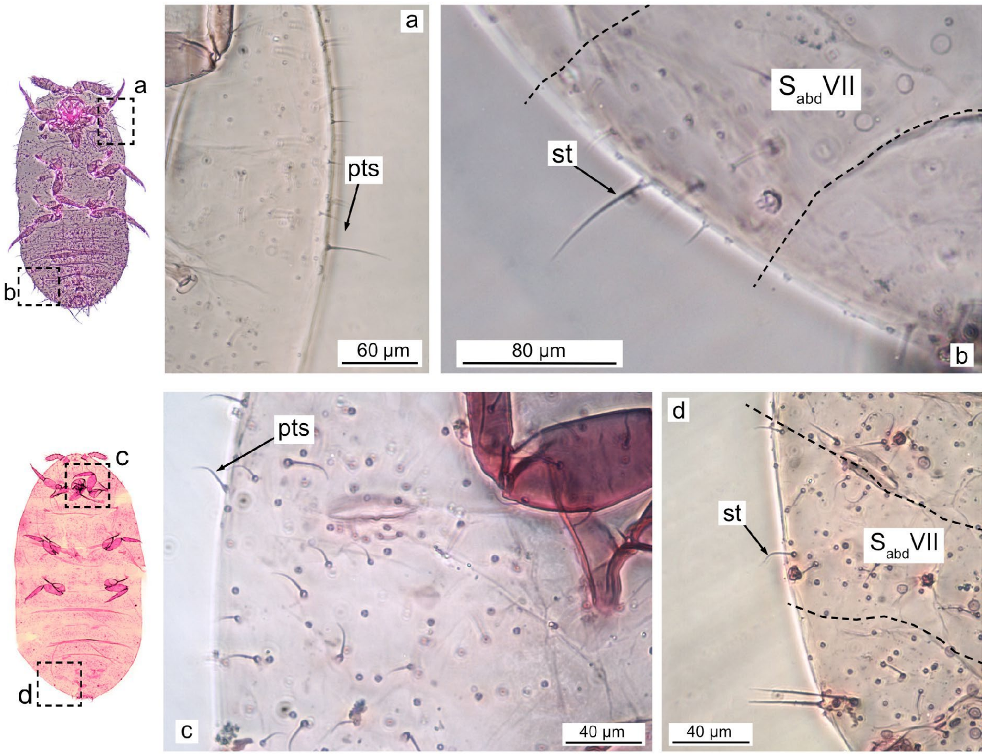

Fig. 53 *Rhizoecus colombiensis*: (a) Body margin with a long seta (pts) (> 40 µm), longer than remaining setae in prothorax; (b) margin of abdominal segment VII (SabdVII) (st). with a long seta (pts) (> 40 µm), longer than remaining setae in abdomen. *Rhizoecus americanus*: (c) Margin of prothorax (pts) with setae of uniform length, shorter than 30 µm; (d) margin of abdominal segment VII (SabdVII) with setae (st) shorter than 30 µm.

No.	Details	Ref.
58(57)	Tritubular ducts of two sizes	*Rhizoecus caladii* Green, 1933
–	Tritubular ducts of three sizes	*Rhizoecus americanus* (Hambleton, 1946)

The species *R. stangei*, which has been recorded only from Mexico and lacks information on its host plant[21] has apparently not been found since its original description[8].

Planococcus citri and *Pl. minor* were listed also by Caballero et al.[2] as literature records. the morphological identification of *P. citri* and *P. minor* needs to be complemented with molecular and geographical analysis to be more accurate[22]. Therefore, the present key considers only identification to the *Planococcus citri-minor* complex.

Furthermore, many specimens of *Dysmicoccus* collected from coffee roots in Colombia have morphological character states that overlap with *Dysmicoccus neobrevipes* Beardsley, 1959, *Dysmicoccus joannesiae* (Costa Lima, 1939) and *Dysmicoccus texensis* (Tinsley, 1900). The first case is a mix of character states of *D. texensis* and *D. neobrevipes*. The number of setae in the abdominal cerarii and the size of oral collar tubular ducts are the most important characters used to differentiate the adult females of *Dysmicoccus* species[8,23]. Adult females of *D. texensis* have a consistent pattern of only two setae in all thoracic and abdominal cerarii, along with a uniform size of oral collar tubular ducts (OC). On the other hand, *D. neobrevipes* varies in the number of setae in the cerarii, ranging from two to seven, accompanied by two distinct sizes of OC. These character states are generally constant among specimens found on the aerial parts of plants. However, among the specimens examined here, while the anal lobe cerarii consistently have two setae on the specimens of *D. texensis* found on the roots, the remaining cerarii display a variable number of setae, notably ranging from two to five, particularly within the abdominal cerarii. Furthermore, the OC of these specimens all are the same size. Regarding the differences in number of setae in the cerarii, Granara de Willink[23] underlined the need of more comprehensive studies to definitively separate these species.

The second case involves *D. joannesiae* and *D. neobrevipes*. These species exhibit similarities in the number of setae on each cerarius (ranging from two to seven setae per cerarius) and differences in the number of clusters of OC along the abdominal margin; *D. joannesiae* has more than 25 clusters of OC and *D. neobrevipes* has fewer than 10 clusters of OC[8]. Granara de Willink also separated these two species by the presence of OC on the thorax and head[23] (present in *D. neobrevipes* and absent in *D. joannesiae*). Within the specimens of putative *D. neobrevipes* studied here, a few had clusters of OC numbering 15 to 20 along the abdominal margin and OC on the thorax and head. The primary challenge with addressing this dilemma lies in the fact that *D. joannesiae* has only been reported on *Joannesia princeps* Vell., 1798 (Euphorbiaceae) in Brazil and on *Annona muricata* (Annonaceae) intercepted in London from Saint Lucia[8,24]. Moreover, there has been no additional morphological variations recorded in the new records of *D. joannesiae* since its initial description in 1932 by Costa Lima. Therefore, the character states defining *D. joannesiae* are based on six type specimens. Based on these arguments, the following taxonomic key considers two species complex groups, namely the *Dysmicoccus texensis-neobrevipes* complex and the *D. joannesiae-neobrevipes* complex.

Following article 31.1.2 of the International Commission of Nomenclature (ICZN), herein we make a change in nomenclature for *Distichlicoccus takumasae* Caballero, 2021. The ending -ae for takumasae is incorrect because the species was dedicated to Dr. Takumasa Kondo (a male coccidologist), and thus the correct ending is -i, hence the species epithet is herein amended to 'takumasai'. The corrected name is *Distichlicoccus takumasai* Caballero, 2021.

Conclusions

After reviewing the species of scale insects associated with coffee roots in Colombia, we have compiled a list of 59 species (Supplemental Table S1). Although this study did not focus on the effect of habit (aerial vs underground) or host plant on the morphology of scale insects, we detected significant morphological variation within facultative hypogeal species. Until further studies allow an understanding of the overlap of character states between *D. texensis* – *D. neobrevipes* and *D. joannesiae* – *D. neobrevipes*, we suggest considering these species as a morphological complex for hypogeal specimens. Further ecomorphological studies should be conducted to determine whether the morphology of a species may differ when feeding on the aerial parts compared when feeding on the underground parts of a host and to try to elucidate what factors trigger those changes, especially in species associated with coffee plants. As for the species complex, further collecting, morphological, and molecular studies should help elucidate these taxonomic problems.

During the literature review performed for this study, we realized that most of the records of species are limited to mentioning the host but not the plant part on which collections were made, however, it is suspected that most species are normally collected from the aerial parts of the plant host. Although this taxonomic key is limited to root-associated species recorded in Colombia, this key could be useful for identifying scale insects associated with coffee in other tropical regions, extending also to species collected from the aerial parts of the hosts.

Author contributions

The authors confirm contributions to the paper as follows: study conception and design: Caballero A, Kondo T; data collection: Caballero A, Kondo T; analysis and interpretation of results: Caballero A, Kondo T; draft manuscript preparation: Caballero A, Kondo T. Both authors reviewed the results and approved the final version of the manuscript.

Data availability

The data (microscopy slides of specimens) that support the findings of this study are available in the Scale insect repository of the entomological museum Universidad Nacional Agronomia Bogota – UNAB, Facultad de Ciencias Agrarias, Colombia. All data generated or analyzed during this study are included in this published article and its supplementary information files.

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Conflict of interest

The authors declare that they have no conflict of interest.

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