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External morphology of *Hemiscorpius lepturus* Peters, 1861 (Scorpiones: Hemiscorpiidae)

Наружная морфология скорпиона *Hemiscorpius lepturus* Peters, 1861 (Scorpiones: Hemiscorpiidae)

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КЛЮЧЕВЫЕ СЛОВА: *Hemiscorpius lepturus*, “созвездие сенсилл”, гребневидный орган, сенсиллы, наружная морфология.

ABSTRACT: *Hemiscorpius lepturus* Peters, 1861 is redefined in both sexes. The detailed external morphologies of chelae, pectinal organs, chelicerae, telsons, and legs I–IV were surveyed with the scanning electron microscope (SEM) in both sexes of *H. lepturus* for the first time. The constellation arrays, bat-like shaped peg sensilla, trichobothria, and the other sensillar and epicuticular structures were described, and their functional morphologies were interpreted considering the species’ habitat and other climatic preferences. The constellation arrays, basiconic sensilla, function as a chemoreceptor (hygro-reception or/and thermo-reception) by its location on the pedipalp in the habitat. The shape of the peg sensilla is remarkably bat-like in both sexes and this shape has not been observed or recorded in any scorpion species, functioning as mechanoreception and contact chemoreception. There are three slit sensilla as single slit, dual and triple slit sensilla on I–IV walking legs, being mechanoreceptors as proprioceptors detecting strain and substrate vibrations during movement. Isolated single slit sensillum was recorded on the chelicerae surface of a scorpion species for the first time.

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РЕЗЮМЕ: Дано переописание *Hemiscorpius lepturus* Peters, 1861 по обоим полам. Впервые с использованием сканирующей электронной микроскопии приведено детальное морфологическое описание клешней педипальп, гребневидных органов, хелицер, тельсона и ног I–IV обоих полов *H. lepturus*. Описаны «созвездие сенсилл», похожие по форме на летучих мышей сенсиллы зубчиков гребневидных органов, трихоботрии, и другие сенсиллы и структуры эпикутикулы, их функциональная морфология интерпретирована с точки зрения биотопа и других климатических предпочтений этого вида. Расположенные на педипальпе «созвездие сенсилл» и базиконические сенсиллы функционируют как хеморецепторы (гигро- и/или терморецепторы). Сенсиллы зубчиков гребневидных органов обоих полов имеют замечательную форму, напоминающую летучую мышь, не обнаруженные у других видов скорпионов, функционируют как механорецепторы и контактные хеморецепторы. На ходных ногах I–IV расположены три щелевидные сенсиллы, единичная, двойная и тройная, которые служат механорецепторами, точнее, проприоцепторами, определяющими напряжение и колебания субстрата во время движения. Впервые у скорпионов обнаружена изолированная единичная щелевидная сенсилла на поверхности хелицер.

Introduction

Scorpiones is the third most populous arachnid order in the world after spiders and pseudoscorpions. This most diverse order currently comprises 22 families, 232 genera and 2740 species [Rein, 2023].

The species that constitute the subject of this study, *Hemiscorpius lepturus* Peters, 1861, belongs to the Hemiscorpiidae family and this family is represented by only one genus and 17 species, distributed in the East Africa, Middle East and eastern parts of Asia — the Arabian Peninsula, Iraq and Iran [Fet, 2000; Lowe, 2010; Lourenço, 2011; Rein, 2023]. *H. lepturus* is distributed in Iran, Iraq, Pakistan and Yemen, stating that it prefers especially hot and humid habitats in Iran. Unlike many other species, it has a cytotoxic venom, causing crucial wounds with necrosis and blisters, and

has no antivenin [Rein, 2023]. Scorpion sense organ is known as eyes, constellation array, slit sensilla, peg sensilla, trichobothria, and setae of different thickness and length, functioning as mechanoreceptors, chemoreceptors (hygro- and thermo-receptors), and proprioceptors [Barth, Stagl, 1976; Foelix, Müller-Vorholt, 1983; Foelix, Schabronath, 1983; Messlinger, 1987; Polis, 1990; Gaffin, Brownell; 1997; Fet *et al*., 2006a, b; Stockmann, Ythier, Fet, 2010; Benli *et al*., 2013]. Foelix & Schabronath [1983] investigated the fine structures of the tarsal sensilla of the legs of *Androctonus australis* (Linneus, 1758), *Euscorpius italicus* (Herbst, 1800) and *Buthus occitanus* Amoreux, 1789, and they described mechanoreceptive and chemoreceptive functions of tarsal sensilla. Foelix & Müller-Vorholt [1983] also studied the peg sensilla on pectines of *Androctonus australis* (Linneus, 1758) and *Euscorpius italicus* (Herbst, 1800). They defined that the mechanoreceptive dendrite terminates and also contact chemoreceptor function of peg sensilla. Fet *et al*. [2006a] described the constellation arrays as a new sensory structure, functioning as chemosensory organ. Benli *et al*. [2013] described the external morphological structures of *Calchas birulai* Fet *et al*., 2009. In the present study, the sensillar and epicuticular structures are determined and their functional morphologies are commented on *H. lepturus* in both sexes.

Material and Methods

Hemiscorpius lepturus, adult specimens, were collected with forceps under stones during day time and UV light on the ground in active motion during night time from Erbil, Heran (36°17′24.10″N, 44°30′03.37″E, 812 m) and Sulaymaniyah, Peramagron (35°44′31.61″N, 45°07′44.41″E, 781 m) provinces in Iraq in June and August of 2022. Specimens were examined using Leica APO8 and illustrated by using a Canon EOS 7D digital camera proposed in Yağmur [2021]. Identification of the specimen was done according to Monod & Lourenço [2005] for Scanning Electron Microscopy (SEM), the chelicerae, pectinal organs, chelae, telsons, carapace and legs I and VI of both sexes were dissected and kept overnight in absolute ethanol. After dehydration, specimens were gold coated in a Quorum SC7620 Sputter Coater. Morphological structures were micrographed at an accelerating voltage of 10kV with a ZEISS Sigma 300 scanning electron microscope in Science Application and Research Center in Van Yüzüncü Yıl University. The examined specimens are preserved in the Arachnida collection of the zoology museum of Hakkari University.

Results

DESCRIPTION (Figs 1–3). MALE. *Carapace.* Carapace is longer than its wide; almost rectangular in shape, but narrows anteriorly after the level of the median eyes, lateral sides nearly parallel until level of median eyes. Anterior margin concave and straight and there is a deep median emargination. Median ocular tubercle shallow and prominently situated anteriorly than middle. The carapace lacks carinae but only weak and smooth superciliary carinae exist. There are three pairs of lateral eyes and the posterior lateral eyes smaller than the 2 anterior lateral eyes. The carapace is densely covered by fine granules with some smooth patches. All margins almost smooth with rare indistinct granules. The anteromedian furrow is narrow and deep, bifurcated anteriorly where it joins the median margination. The posteromedian furrow is wide and bifurcated as an inverted T-shaped at posterior edge. Both these two furrows are located in sagittal-shaped depressions and are fused and continuous. Posterolateral furrows shallow and enlarged posteriorly, posterior tips joint to posteromedian furrow at bifurcated tips. *Chelicerae.* Teeth order fits Scorpionidae described by Vachon [1963]; teeth are sharp; fixed bears subdistal, basal denticles smaller and median teeth; movable finger bears distal, subdistal, medial and basal teeth. *Sternum*. Sternum pentagonal, type 2 [Soleglad, Fet, 2003], longer than wide, smooth, median furrow deep. *Pectines and genital operculum*. Genital operculum elliptical, composed of 2 ovoid plates. Pectines with 14-16 teeth, usually 15-15. *Mesosoma*. Tergites I–VI are wider than long, but tergite VII is longer than wide. Tergites I–II without carinae, tergites III–IV with reduced median carina, tergite VII with a reduced median carina and a pair of moderate lateral carinae. Surface of tergites finely shagreened and lustrous with dense minute punctate. Sternite III–VI smooth and lustrous with minute punctate without granulation and carinae. Sternite VII smooth and lustrous with minute punctate fine granulation laterally. *Metasoma.* Extremely elongated and slender, rough, with sparsely fine granules. Covered scattered long and distinct macrosetae. Depth of segments increases posteriorly on segments I–IV with 7 prominent carinae and longitudinal dorsal furrows. Dorsal carinae bear costate spiniform granules that gradually increase posteriorly to segment. Lateral carinae moderate and smooth without granules. Ventrolateral carinae strong and smooth on segments I–II and with costate and fine granules on segments III–IV. Ventromedian carinae weak and smooth in segment I, moderate and smooth in segment II–III, moderate and faintly granular in segment IV. V with 5 strong carinae. Dorsal carinae with costate and small spiniform granules. Ventrolateral and ventromedian with costate and small granules. *Telson.* Vesicle elliptical and strongly elongated. A pair of rounded tuberculiform projections exist on each side at base of aculeus. Lateral and dorsal surfaces with irregularly conspicuous granules. Covered sparse macrosetae. Aculeus short and stout, strongly and abruptly curved. *Pedipalp*. Pedipalp consists of somewhat short segments. Covered scattered macrosetae. Femur short and thin, flattened dorsoventrally, pentacarinate; dorsointernal and ventrointernal carinae strong with fused big granules; ventrointernal, ventroexternal and ventromedian carinae moderate with spaced granules. Surface rough with densely fine granules. Femur bears 3 trichobothria; *d* located on posterior of dorsal surface; *i* located on posterior internal surface and *e* located on posterior of external surface. Patella short and thin, flattened dorsoventrally with 7 carinae. Exteromedian carina weak and nearly smooth, other carinae moderate and as fused swollen and coarse granules. Dorsal and ventral patellar spurs located posteriorly and form large conical granules. Dorsal, ventral and external surfaces rough with densely fine granules, internal surface shagreened, with small, scattered granules. A total of 19 trichobothria exist on patella and orthobothriotaxic. Trichobothrium *d1* located posterior tip of dorsointernal carina; d_2 located medially on patella exterior edge of dorsointernal carina; *i* located on internal surface of patella, interior edge of dorsointernal carina, anteriorly close to d_2. External (*e*) trichobothria: Trichobothria series

Fig. 1. *Hemiscorpius lepturus* Peters, 1861. A, B — male, C, D — female: A, C — dorsal view; B, D — ventral view. Scale bar 1 cm.
Рис. 1. *Hemiscorpius lepturus* Peters, 1861. A, B — самец, C, D — самка: A, C — дорсально; B, D — вентрально. Масштаб 1 см.

eb composed of 5 trichobothria, *esb* series 2 trichobothria, *em* series 2 trichobothria, *et* series 3 trichobothria. Ventral (*v*) trichobothria composed of 3 trichobothria, located on posterior half of patella, exterior edge of the ventroexternal carina. *Chela*. Somewhat elongated manus, short fingers, with 5 distinct carinae; dorsointernal carina weak with distinct conical and spaced granules; digital carina weak and smooth, more distinct posteriorly and reach to movable finger; dorsoexternal carinae strong and smooth, ventrointernal carinae moderate, rounded and smooth, bear many fine granules; ventroexternal carina strong, with fused rough granules basally and smooth distally. Dorsal surface rough with densely fine granules and smooth patches. Internal surface shagreened with distinct conical granules. External rough with dense and fine granules. A total of 15 trichobothria are present on chela manus. Trichobothrium *Db* located basally on dorsoexternal carinae; *Eb* series located basally on external surface with 3 trichobothria. Trichobothrium *Esb*

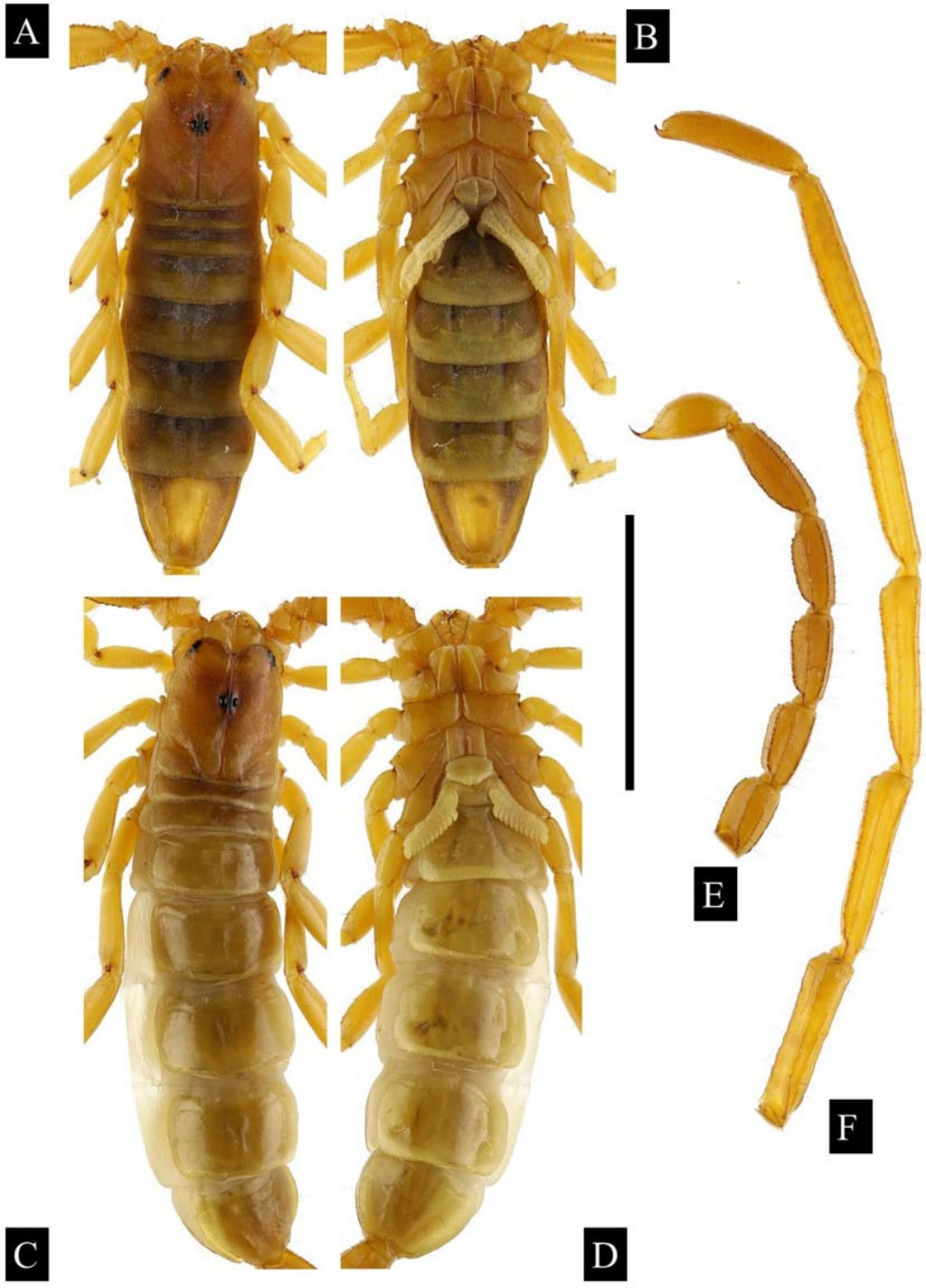

Fig. 2. *Hemiscorpius lepturus* Peters, 1861. A, B, F — male, C, D, E — female: A, C — dorsal view of carapace and mesosoma; B, D — ventral view of carapace and mesosoma; E, F — lateral view of metasoma. Scale bar 1 cm.

Рис. 2. *Hemiscorpius lepturus* Peters, 1861. A, B, F — самец, C, D, E — самка: A, C — карапакс и мезосома, дорсально; B, D — карапакс и мезосома, вентрально; E, F — метасома, латерально. Масштаб 1 см.

located close to *Eb* series. *Est* located distally and, close to *Et* series; *Et* series composed of 5 trichobothria, *Et1* located ventrally, *Et2-5* located externally; *V* series composed 4 trichobothria, *V1* and *V2* located anteriorly and *V3* and *V4* located posteriorly, all trichobothria located linearly. Fingers slightly shorter than manus, smooth anteriorly, fine granular basally, curved inward. Movable finger with weak scalloping. The dentate margin of fingers composed of two parallel, serrate rows denticles becoming fused basally with regular intervals of bigger granules. A total of 11 trichobothria exist on fingers; trichobothrium *Dt* located at basal on dorsal surface of fixed finger; trichobothrium *db*

Fig. 3. *Hemiscorpius lepturus* Peters, 1861. A, B — male, C, D — female: A, C — retrolateral view of pedipalp; B, D — prolateral view of pedipalp. Scale bar 1 cm.

Рис. 3. *Hemiscorpius lepturus* Peters, 1861. A, B — самец, C, D — самка: A, C — педипальпа, ретролатерально; B, D — педипальпа, пролатерально. Масштаб 1 см.

located on internal surface equal to *eb*, at posterior half of fixed finger; trichobothria *dsb, dst* and *dt* located on dorsal surface linearly, at anterior half of finger; trichobothrium *eb* located on external surface in basal half of fixed finger; trichobothria *esb*, *est* and *et* located at posterior half of fixed finger linearly; *esb*, *est* and *et* located equally to *dsb*, *dst* and *dt*, respectively; *it* and *ib* located close to middle of fixed finger internally. *Legs*. Femur and tarsus smooth and lustrous dorsally with scattered macrosetae. Tarsi two rows of stout spiniform setae.

FEMALE. The characters different from male are as follow. Carapace stockier than in male. Tergite and sternite VII of mesosoma as wide as long. Metasoma considerably shorter than with shorter segments in male. Carinae generally more granular and distinct. Telson: Vesicle ovoidal and globular, little elongated. Aculeus thinner and narrow slightly than male without tubercles at its base. Pedipalp: femur, patella, manus and fingers shorter and stockier than in males.

EXTERNAL MORPHOLOGY OF CHELAE (Figs 4, 5). There are constellation arrays at the tip of the chelal fixed fingers on retrolateral surfaces in both sexes (Fig. 4A, B). The clusters of sensillar structures in constellation arrays consist of 7 basiconic sensilla in males and 6 basiconic sensilla in females (Fig. 4C, D). Each basiconic sensillum is located in a large pit-shaped socket. The average length of these basiconic sensilla in the male is 5.07 µm and the width of the concave socket to which it is attached is 13.8 µm. The average length of these basiconic sensilla in the female is 8.07 µm and the width of the concave socket to which it is attached is 16.4 µm. There are 2 wax openings close to each peg sensillum, one of them in concave area with peg sensillum and one of them is outside the pit area (Fig. 4E, F). There are few trichobothria located at irregular intervals, especially on the chelal fixed fingers (Figs 4A, B; 5C, D). Each trichobothrium is filiform and the socket comprises of intertwined circular structures. The average length of these trichobothria in the male is 0.94 mm, and in the female is 1.47 mm (Figs 4A, B; 5A, B, C, D). The cuticular surface of trichobothria is longitudinally corrugated as in the lower-right corner picture (Fig. 5D). The prolateral and retrolateral surfaces of chelae have pattern in the form of depressions in irregular annular form in both sexes (Figs 4A, B; 5A, B, H). The chela surface is covered with a large number of wax openings of different widths in both sexes (Fig. 5E, F). There are weak falciform hairs as in form sensilla trichodea at the tip of the fixed and movable chelal fingers in both sexes (Figs 4A, B; 5A, B, G) and the four-piece setae as in form non-socketed sensilla chaetica on the distal end of fixed chelal finger of male (Fig. 5G).

EXTERNAL MORPHOLOGY OF CHELICERAE (Figs 6, 7). The movable fingers of the chelicerae are characteristically bifurcated in both sexes (Figs 6A, B; 7A–B). There are 3 setae in form of weak and socketed sensilla trichodea that shorten ventrally, and there is a single slit sensillum typically lips-shaped on the shortest seta of these on the retrolateral surfaces of the both sexes (Fig. 6A–B, E–F). There is also falciform hairs sparsely located on retrolateral surfaces of movable fingers in both sexes (Fig. 6C–D). There are many wax openings on the retrolateral surfaces in both sexes (Fig. 6C–G). The cuticular pattern of retrolateral surface is tubercular as in Fig. 6H. There are numerous non-socketed serrate setae on the prolateral surface of chelicerae (Fig. 7C–D) and these setae are denser in male than female (Fig. 7A–B).

EXTERNAL MORPHOLOGY OF PECTINAL ORGAN (Fig. 8). The pectines are paired comb-like structures near the coxae of the 4th pair of legs on the ventral sides in both sexes. The numbers of pectinal teeth are 14–15 in males and 10–11 in females (Figs 2B, D; 8A–B). The number of peg sensilla on each pectinal tooth is greater in males (Fig. 8C–F). There are inverted bat-like peg sensilla on the ventral surface of each pectinal tooth. The average length of peg sensilla in males is 6.44 µm and in females is 3.62 µm. The distal edges of each peg sensilla are elongated into bat ears. These distal edges in males are longer and more pointed than in females (Fig. 8G–H).

EXTERNAL MORPHOLOGY OF EYES (Fig. 9). The specimens typically contain two pairs of eye-groups referred to as median eyes and lateral eyes. The carapace has a longitudinal line passing through the middle of the median eyes from anterior to posterior in both sexes (Fig. 9A–B). The gap between the median eyes is greater in male (259 µm) than female (172 µm). There are two setae behind the median eyes in form sensilla trichodea which are thin walled and small socketed. These form setae are found in anterior and lateral sides of carapace. The three lateral eyes are found on both sides in both sexes (Fig. 9C–D). The posterior lateral eye is smaller than the anterior two lateral eyes. The dorsal surface of the lateral eyes is covered with numerous wax openings (Fig. 9C–E). The cuticular pattern of the carapace is in the form of a drop of liquid that has fallen to the ground and slight pitting (Fig. 9F).

EXTERNAL MORHOLOGY OF STERNITE (Fig. 10). Genital sternite are as in Fig. 10A in male and Fig. 10B in female. There are infrequent short, puny and socketed setae in form sensilla trichodea (Fig. 10A–B). There are a few and different sizes single slit sensilla (Fig. 10C), and numerous wax openings also on sternite surfaces (Fig. 10C–D). The species have four pairs of elliptical stigmata (spiracles) in both sexes (Figs 2A–D; 10E–F). These spiracles are closed and the slightly dimpled surface in the middle has

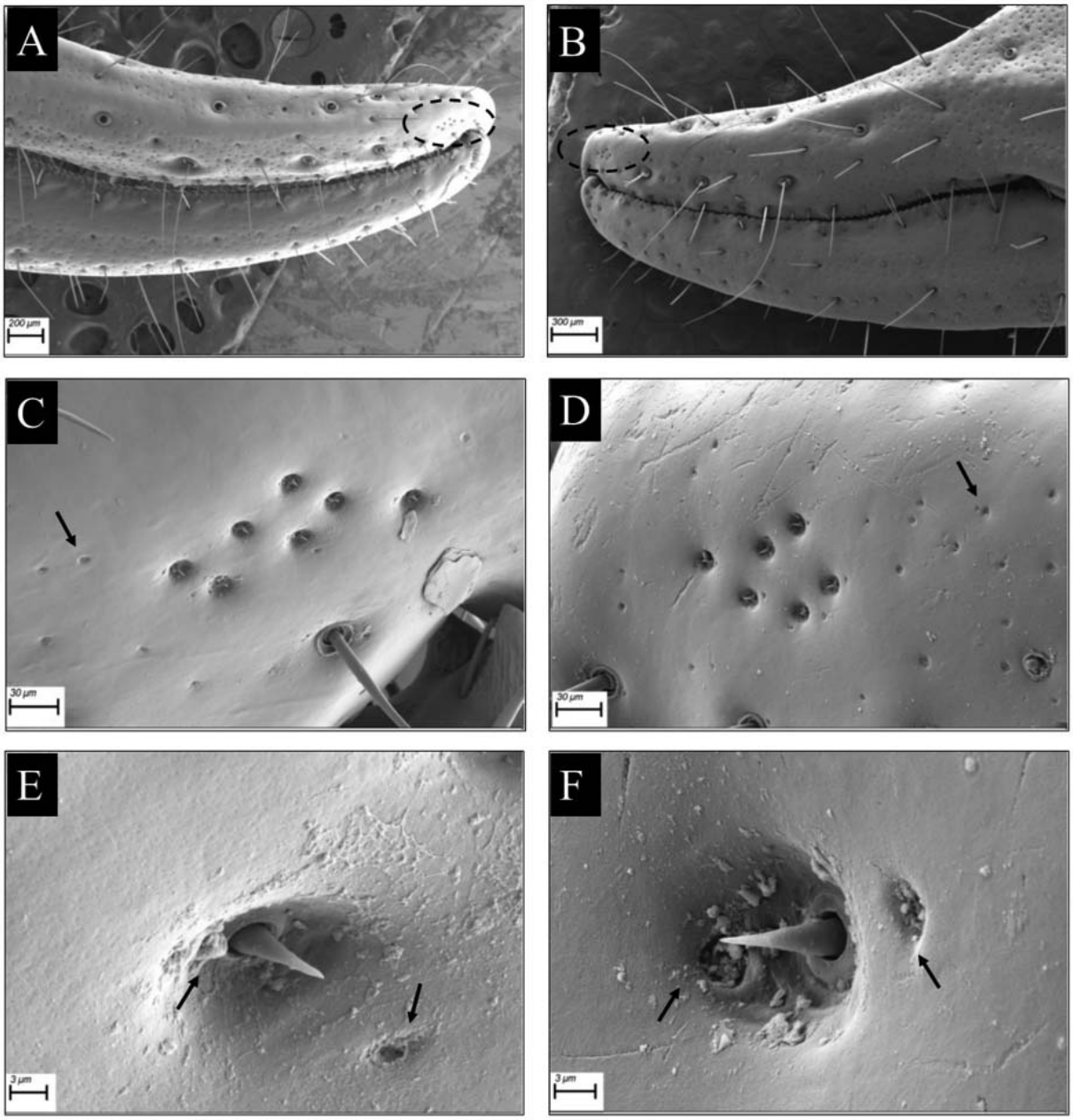

Fig. 4. *Hemiscorpius lepturus* Peters, 1861. A, C, E — male, B, D, F — female: A, B — chela of pedipalps in retrolateral view (areas of constellation array indicated by circles); C, D —constellation array (arrows show the wax openings); E, F — single basiconic sensillum with wax openings (indicated by arrows). Scale bars: A — 200 µm, B — 300 µm, C, D — 30 µm, E, F — 3 µm.

Рис. 4. *Hemiscorpius lepturus* Peters, 1861. A, C, E — самец, B, D, F — самка: A, B — клешня педипальп, ретролатерально (области «созвездия сенсилл» обведены кружками); C, D — «созвездие сенсилл» (стрелки показывают отверстия восковых желез); E, F — единичная базиконическая сенсилла с отверстиями восковых желез (показаны стрелками). Масштаб: A — 200 мкм, B — 300 мкм, C, D — 30 мкм, E, F — 3 мкм.

multiple hexagonal honeycomb-like cuticular patterns (Fig. 10E–F).

EXTERNAL MORPHOLOGY OF TELSON (Fig. 11). The body part of telson in male and female are completely different. The telson body part is wider in the female (1.6 mm) than the male (1.35 mm). While it is flatter from distal to proximal in the male, it is cambered in the middle in the female. The distal part of telson in male is with two lobes (Fig. 11A, C). The length of the venom sting is longer in the male (0.58 mm) than in the female (0.47 mm) (Fig. 11C–D). On the telson surface, large tubercular structures are found in both sexes, while the male has a smaller structure and more tubercular cuticular patterns (Fig. 11A–C). There are long and perpendicular setae, and short and placed at irregular intervals setae on the telson surface as form in sensilla trichodea (Fig. 11A–D).

The other metasomal segments are more swollen and setose in females than males (Fig. 12A–B). There are special cuticular patterns in both sexes, contained tubercular structures and epicuticular protrusions in form of microtrichia (Fig. 12C–E).

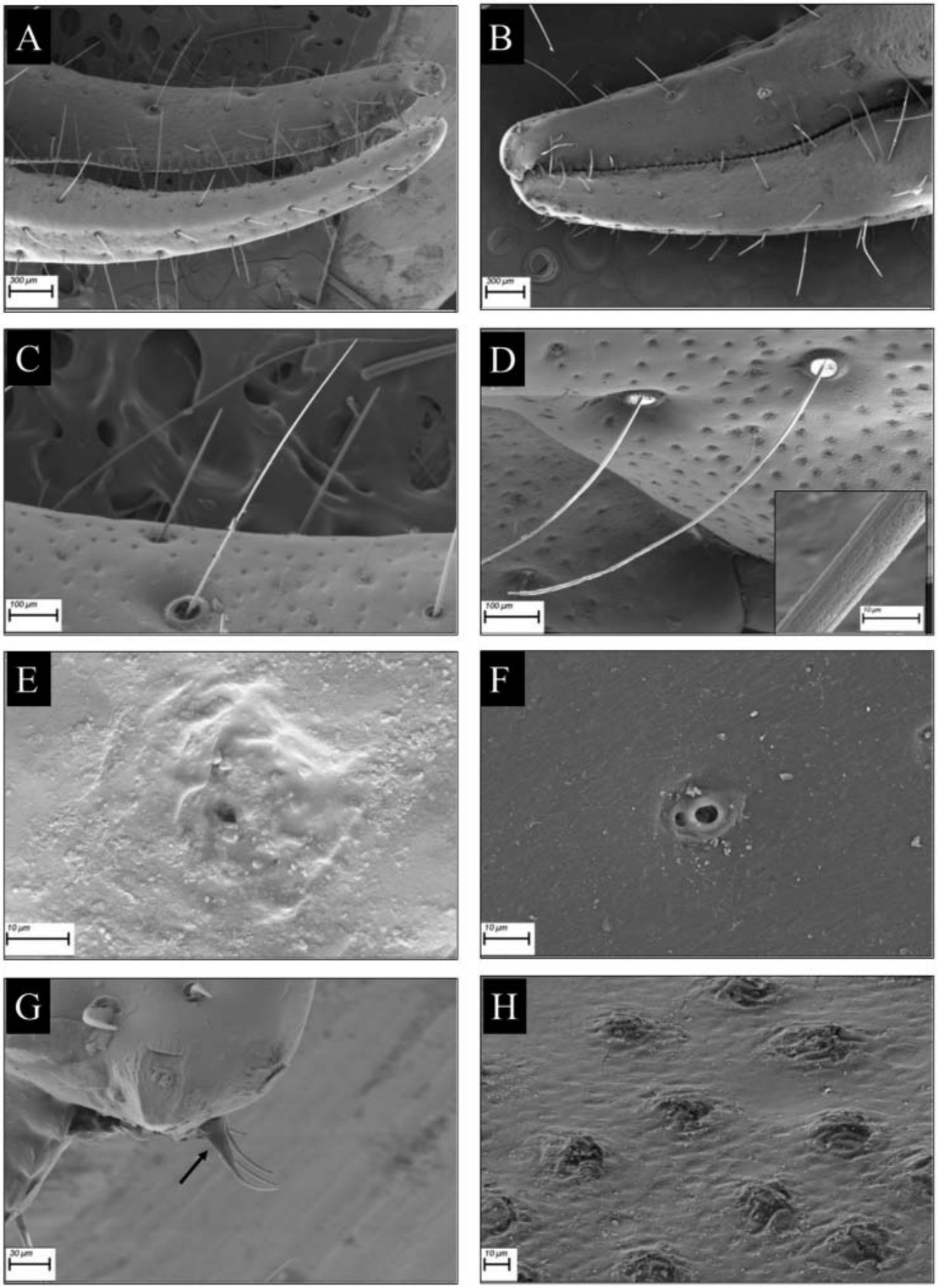

Fig. 5. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A, B — chela of pedipalps in prolateral view; C, D — trichobothria (picture in the lower-corner shows the detail of trichobothrium surface); E, F — wax openings; G — falciform hairs and four-piece seta (indicated by arrow) on the tip of chelar fixed finger; H — cuticular patterns on chelar surface. Scale bars: A, B — 300 μm, C, D — 100 μm, G — 30 μm, E, F, H — 10 μm.

Рис. 5. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самце, B, D, F, H — самка: A, B — клешня педипальп, пролатерально; C, D — трихоботрии (в нижнем углу показана деталь поверхности трихоботрии); E, F — отверстия восковых желез; G — серповидные волоски и четырехчастная сета (показана стрелкой) на вершине неподвижного пальца клешни педипальп; H — типы кутикулы на поверхности клешни педипальп. Масштаб: A, B — 300 мкм, C, D — 100 мкм, G — 30 мкм, E, F, H — 10 мкм.

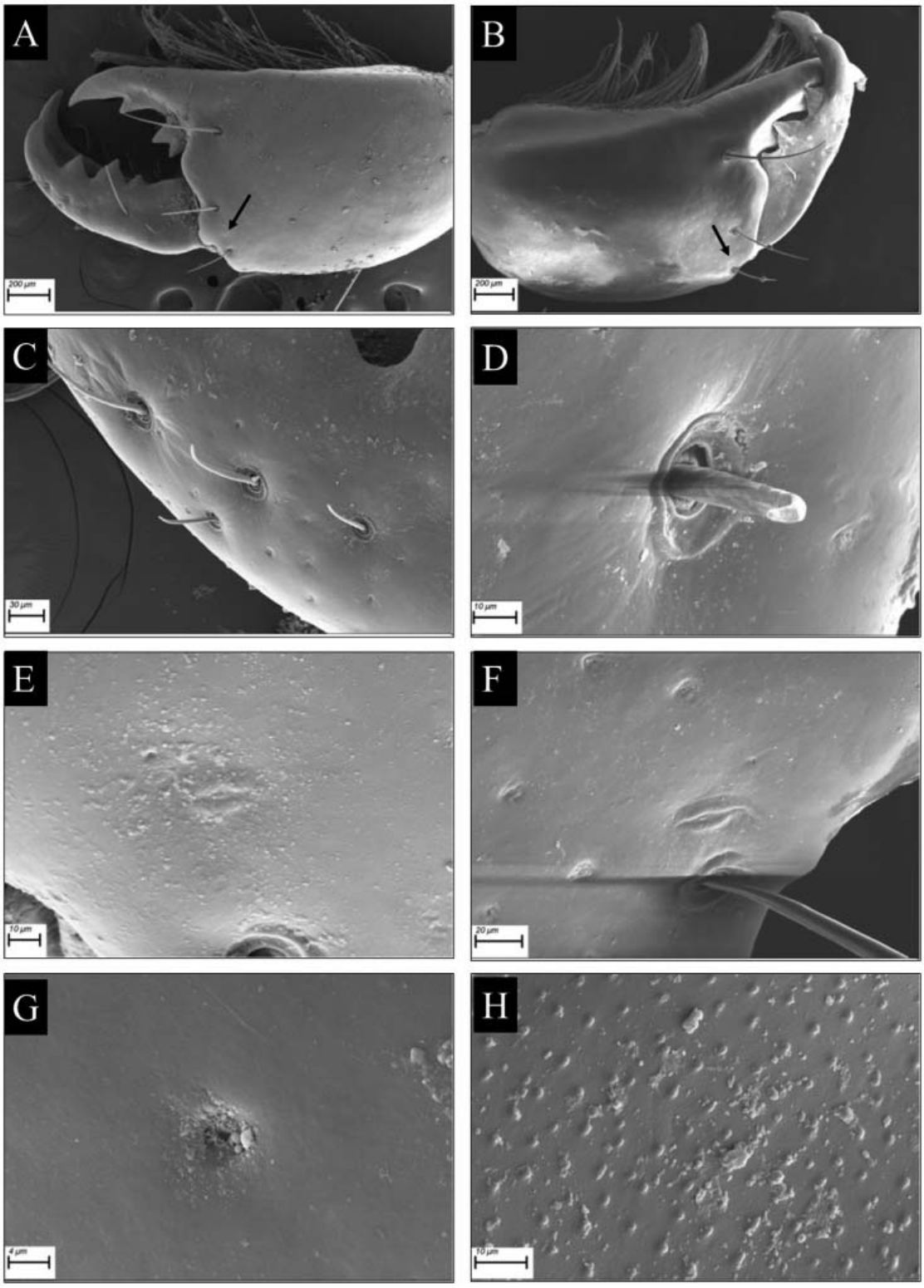

Fig. 6. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A, B — chelicera in retrolateral view (arrows show the single slit sensillum, area); C, D — sensilla trichodea; E, F — single slit sensillum on manus surface; G — wax opening on chelicera surface; H — cuticular pattern on chelicera surface. Scale bars: A, B — 200 μm, C — 30 μm, D, E, H — 10 μm, F — 20 μm, G — 4 μm.

Рис. 6. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H — самка: A, B — хелицера, ретролатерально (стрелки показывают область единичной щелевидной сенсиллы); C, D — волосовидная сенсилла; E, F — единичная щелевидная сенсилла на поверхности основания клешни педипальп; G — отверстие восковой железы на поверхности хелицеры; H — тип кутикулы на поверхности хелицеры. Масштаб: A, B — 200 мкм, C — 30 мкм, D, E, H — 10 мкм, F — 20 мкм, G — 4 мкм.

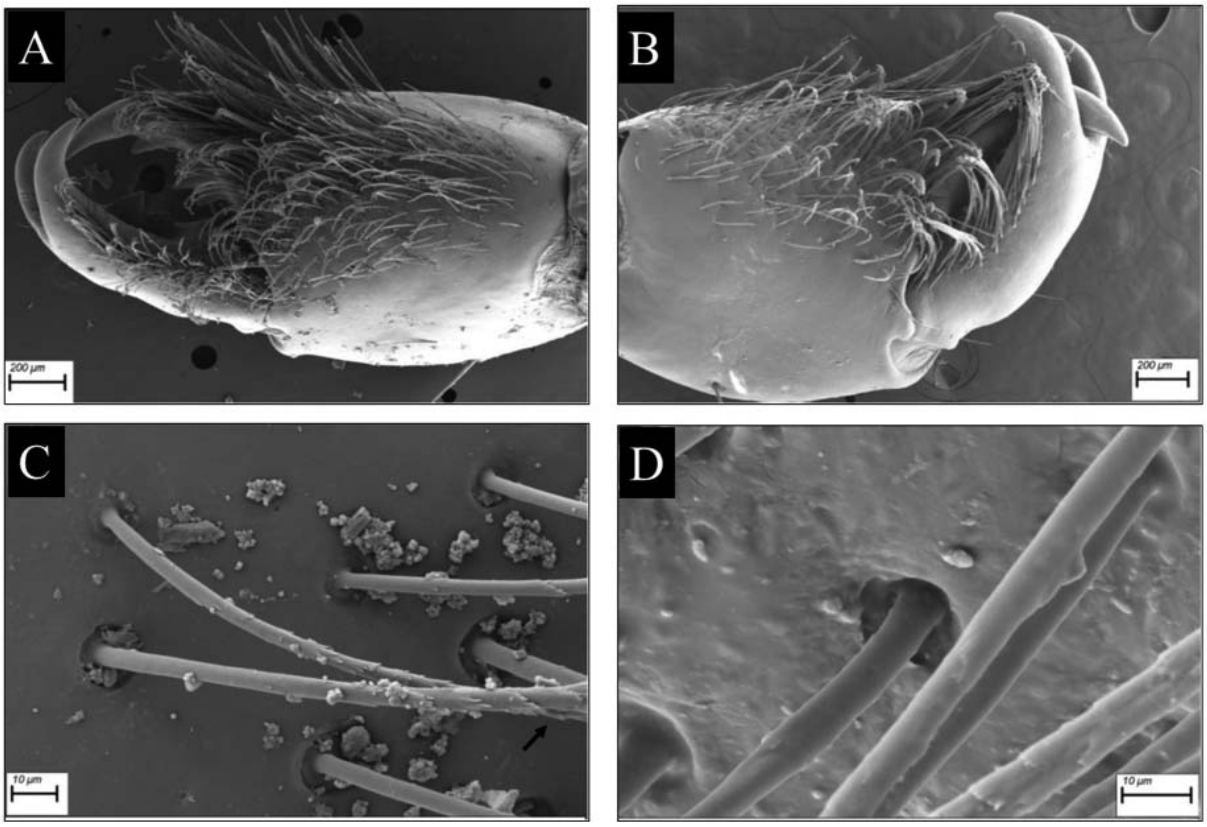

Fig. 7. *Hemiscorpius lepturus* Peters, 1861. A, C — male, B, D — female: A, B — chelicera in prolateral view; C, D — sensilla chaetica without socket (arrow shows serrated surface of sensilla). Scale bars: A, B — 200 µm, C, D — 10 µm.

Рис. 7. *Hemiscorpius lepturus* Peters, 1861. A, C — самец, B, D — самка: A, B — хелицера, пролатерально; C, D — хетовидная сенсилла без ямки (стрелка показывает зубчатую поверхность сенсиллы). Масштаб: A, B — 200 мкм, C, D — 10 мкм.

EXTERNAL MORPHOLOGY OF WALKING LEGS (Figs 13–16). The cuticle surfaces of legs I–IV are typically covered with different length and thickness setae. There is one prominent basitarsal (pedal) spur on each leg (Figs 13B; 14B; 15A; 16A). Three types setae are found on legs surfaces. Two are in form sensilla chaetica and one is in for sensilla trichodae. The first type of chaetical sensilla is short and thick setae on the ventral side of telotarsi in both sexes, which have prominent socket structures with knurled distal end (Figs 13A, B, D; 14A, B; 15A–D, 16A, B, D). The socket protrusion elongates from proximal to distal, thus allowing the setae to stay close to the surface and only move sideways. The other chaetical sensilla is long, sparse and thick setae with restricted movement, having irregular socket structures, on legs surfaces in both sexes. The trichodeal sensilla are short and weak setae, in very rare numbers, found on the entire legs surfaces in both sexes (Fig. 14C). The cuticle surface of both the chaetical and trichodeal sensilla is longitudinally grooved (Figs 13A; 14D; 15C; 16D). There are also pointed and robust cuticular protrusions called spinules on legs tarsi in both sexes (Figs 13B, D; 14B; 15A, C; 16A, D). The surfaces of each leg are covered with numerous wax openings in both sexes (Figs 13E–H; 14E–G; 15E, H, J; 16C, E–I). There are numerous single, dual and triple lip-shaped slit sensilla especially distal parts of leg segments. The single sensilla are located on the distal part of telotarsus of 2nd leg in male (Fig. 14C) and on the distal part of basitarsus of 4th leg in both sexes (Fig. 16H, J), and their length varies between 74–106 µm. The dual slit sensilla are located on the distal part of tibia of 1st legs, 3rd legs and 4th legs (Figs 13E, F; 15E, F; 16G, I), the distal part of trochanter of 2nd legs and 3rd legs (Figs 14E, F; 15H, J) in both sexes. The triple slit sensilla are located on the distal part of pretarsus of 1st legs, 3rd legs, and 4th legs (Figs 13G, H; 15G, I; 16E, F), and the distal part of tibia of 2nd legs (Fig. 14H).

Discussion

This study provided the detailed external morphology of *Hemiscorpius lepturus* Peters, 1861, the scorpion with cytotoxic venom. Typically, three types aporous sensilla are detected on different body part surface on species in both sexes: Sensilla basiconica (SB), Sensilla chaetica (SC), Sensilla trichodea (ST). McIver [1975] and Altner & Prillinger [1980] indicated that these aporous sensilla, lacking pores on sensilla tips and cuticle walls, have mechanosensitive functions as exteroceptors. Foelix & Schabronath [1983] suggested that long, straight hairs and short, stiff hairs are mechanoreceptive, but short, curved hairs are chemoreceptive. Considering these, SC on chelar surfaces and I–IV legs cuticle surfaces

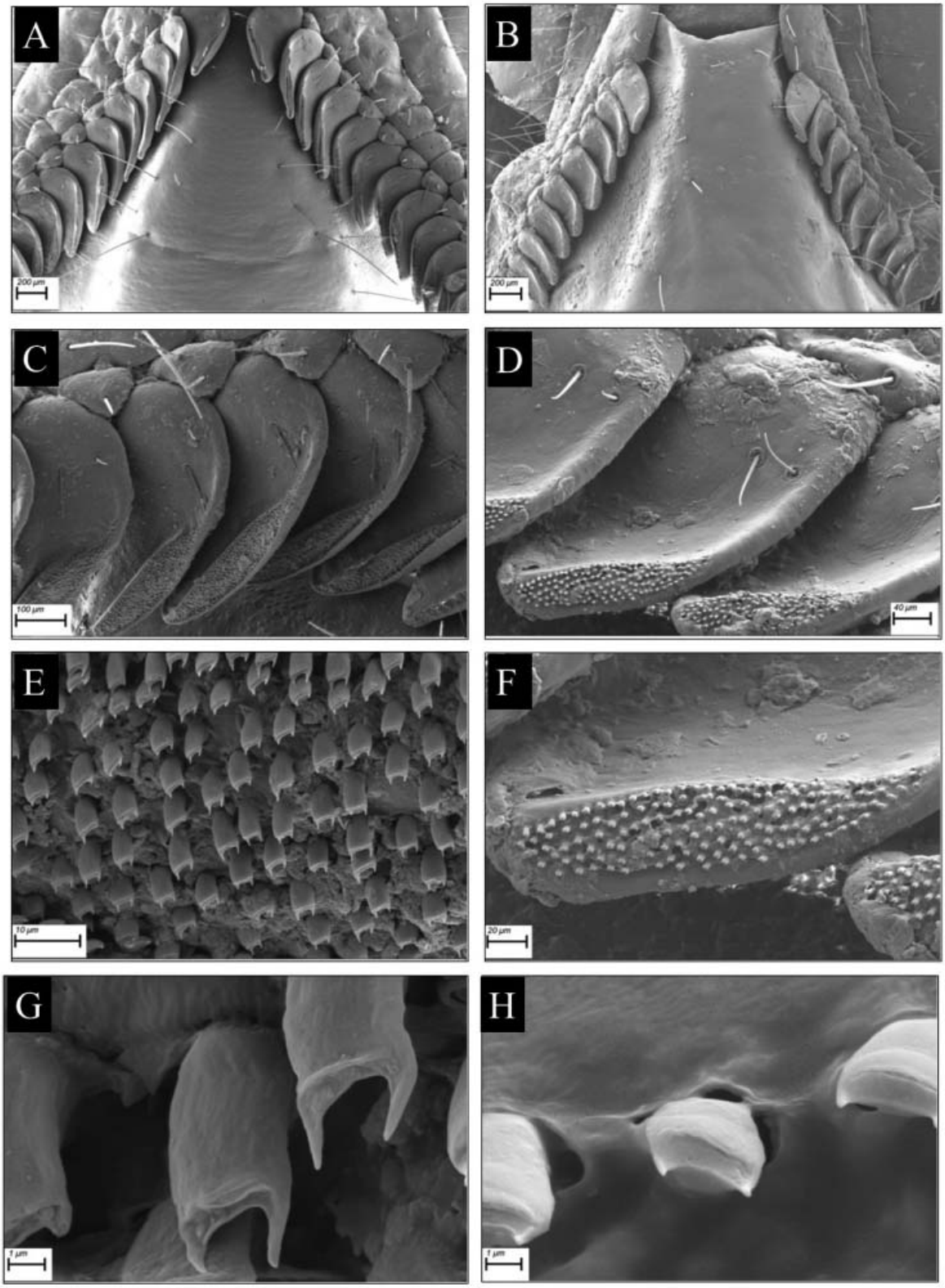

Fig. 8. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A, B — pectinal organ; C, D — pectinal teeth; E, F — peg sensilla; G, H — peg sensilla in detail. Scale bars: A, B — 200 μm, C — 100 μm, D — 40 μm, E — 10 μm, F — 20 μm, G, H — 1 μm.

Рис. 8. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H — самка: A, B — гребневидный орган; C, D — зубец гребневидного органа; E, F — сенсиллы зубчиков гребневидных органов; G, H — то же, детализировано. Масштаб: A, B — 200 мкм, C — 100 мкм, D — 40 мкм, E — 10 мкм, F — 20 мкм, G, H — 1 мкм.

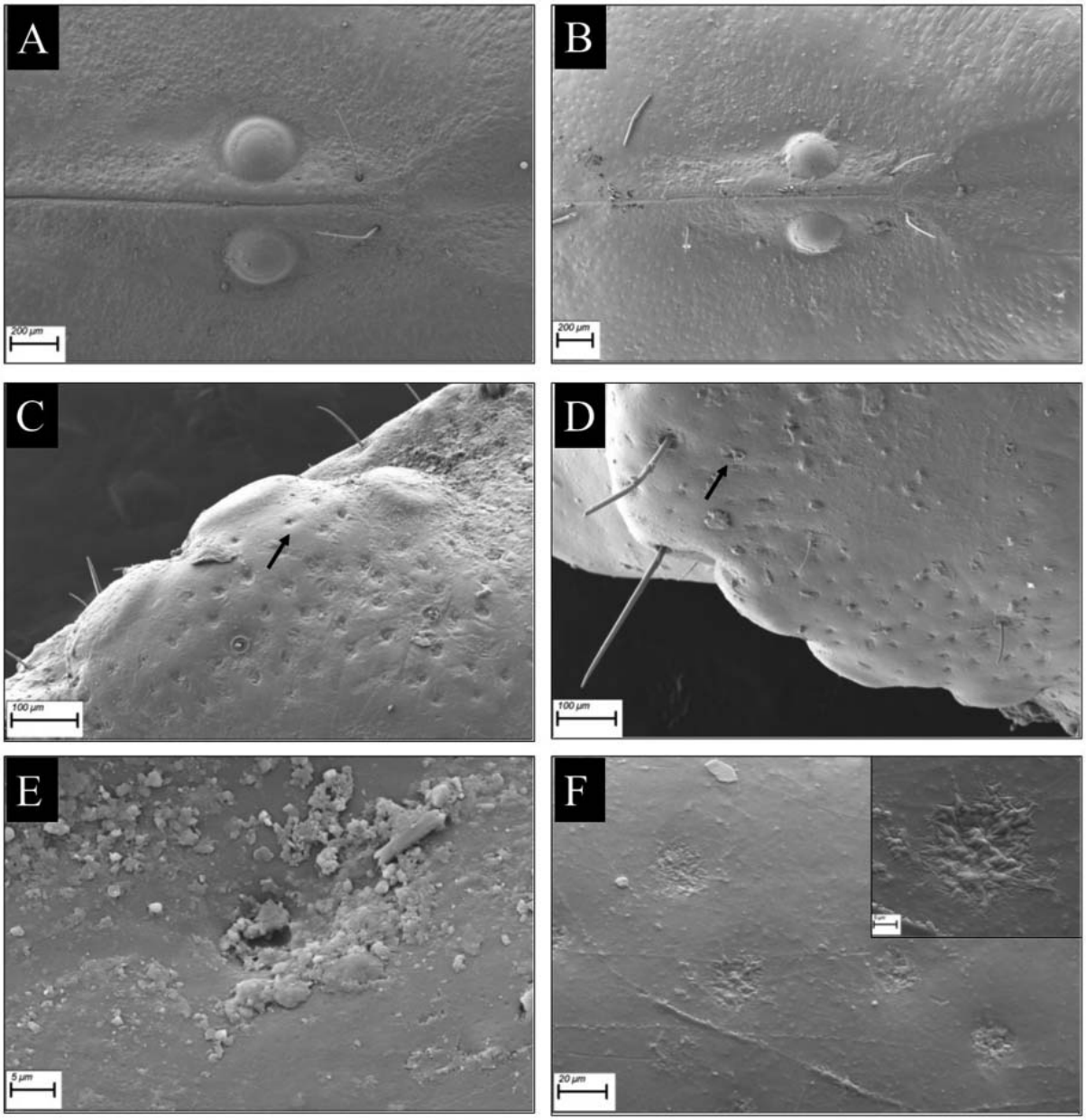

Fig. 9. *Hemiscorpius lepturus* Peters, 1861. A, C, E — male, B, D, F — female: A, B — median eyes; C, D — lateral eyes (arrows show wax openings); E, F — cuticular pattern on carapace surface (picture in the upper-corner shows detail of cuticular pattern). Scale bars: A, B — 200 µm, C, D — 100 µm, E — 5 µm, F — 20 µm.

Рис. 9. *Hemiscorpius lepturus* Peters, 1861. A, C, E — самец, B, D, F — самка: A, B — срединные глаза; C, D — боковые глаза (стрелки показывают отверстия восковых желез); E, F — тип кутикулы на поверхности карапакса (в верхнем углу — детализированное изображение). Масштаб: A, B — 200 мкм, C, D — 100 мкм, E — 5 мкм, F — 20 мкм.

must function as mechanoreceptors during walking, searching substrate on the ground, and chelar contact for mating behavior and nutrition. The SC and ST on chelicerae should most likely act as a contact chemoreceptor for gustation, additionally, the non-socketed serrated SC must function as a comb to prevent nutrient loss during feeding. The four-pieced non-socketed SC at the tip of chelar fixed finger in male *H. lepturus* may function as a mechanoreceptor in determining the location of the female during the mating period.

Trichobothria must also belong to trichoid sensilla with its long, thin, and spindly structures, and the epicuticular lamellar cup-shaped socket structures allow circular motion in the air. Trichobothria are mechanoreceptors [Messlinger, 1987; Root, 1990], responding predominantly to weak air currents and locating the prey. *H. lepturus* was collected in semi-arid localities in hot dry summers in the average temperature range of 22–42 °C. Trichobothria of different lengths at different intervals are found on

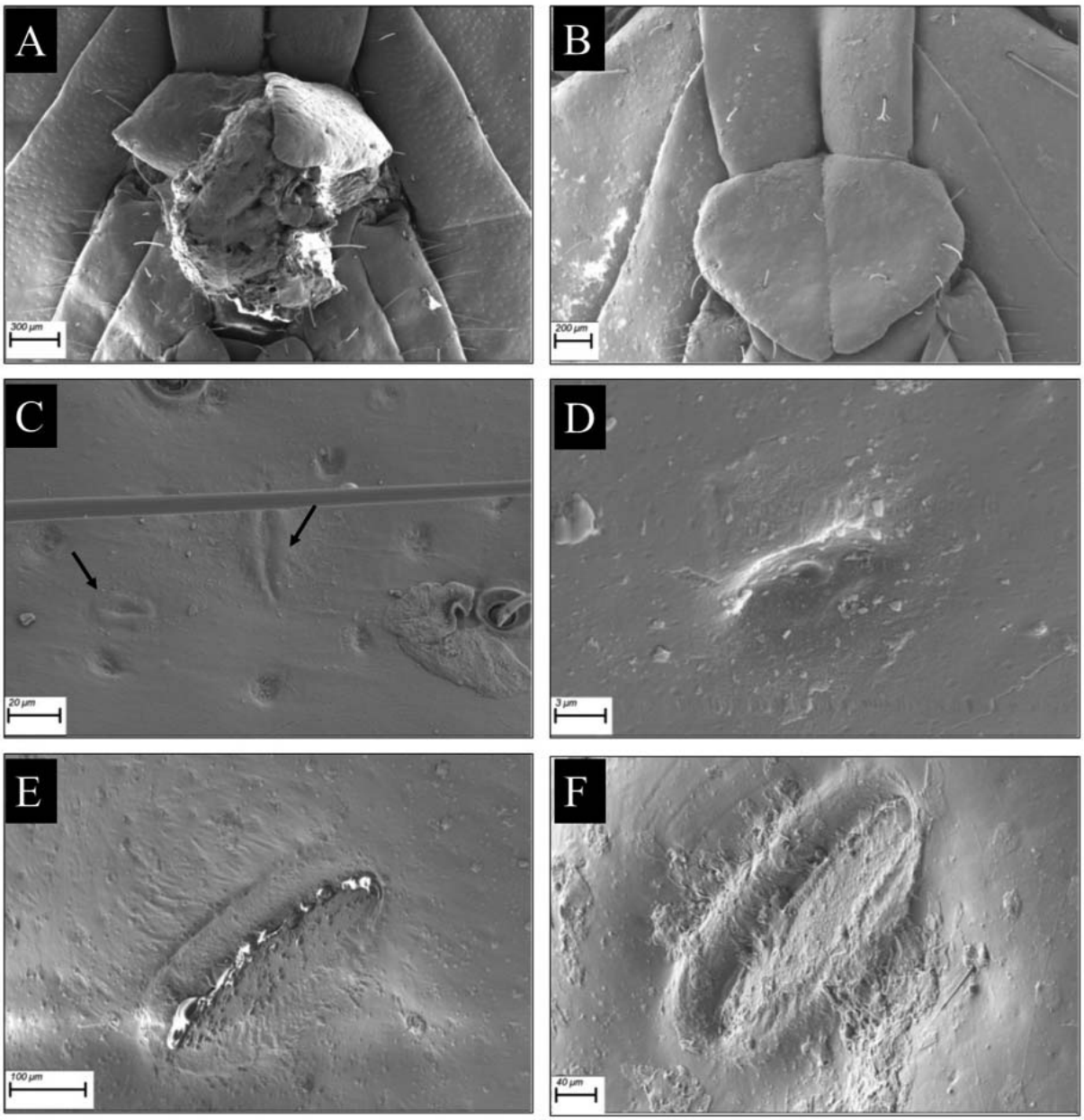

Fig. 10. *Hemiscorpius lepturus* Peters, 1861. A, C, E — male, B, D, F — female: A, B — genital operculum; C — dual slit sensilla indicated by arrows on the ventral side of coxa of 3rd leg; D — wax opening; E, F — stigma. Scale bars: A — 300 µm, B — 200 µm, C — 20 µm, D — 3 µm, E — 100 µm, F — 40 µm.

Рис. 10. *Hemiscorpius lepturus* Peters, 1861. A, C, E — самец, B, D, F — самка: A, B — половая крышечка; C — двойные щелевидные сенсиллы показаны стрелкой на вентральной стороне тазика 3-й пары ног; D — отверстие восковой железы; E, F — стигма. Масштаб: A — 300 мкм, B — 200 мкм, C — 20 мкм, D — 3 мкм, E — 100 мкм, F — 40 мкм.

whole pedipalp surfaces of species and also function as anemotactic orientation and localization prey. The epicuticular protrusions as called microtrichia on the metasomal segments may act as waterproof resisting structures to keep moisture-related droplets away from the cuticle surface in hot climates, considering metasomal segments are the part that stays in the air during the active movement of the scorpion.

The constellation array, located on the external aspect of the distal portion of the chelar fixed finger of the pedipalp is described as a chemosensory sensilla/organ in scorpions [Fet *et al*., 2006a]. They showed the constellation arrays in 23 different species belonging to 12 families and 23 genera. It is stated that the number of sensilla in this sense organ, which consists of different numbers of sensilla, varies between 1–15. The number of these basiconic sensilla in the array cluster is 6 in females and 7 in males in *H. lepturus* in the present study. Fet *et al*. [2006b], also analyzed the constellation arrays in four genera species in Vae-

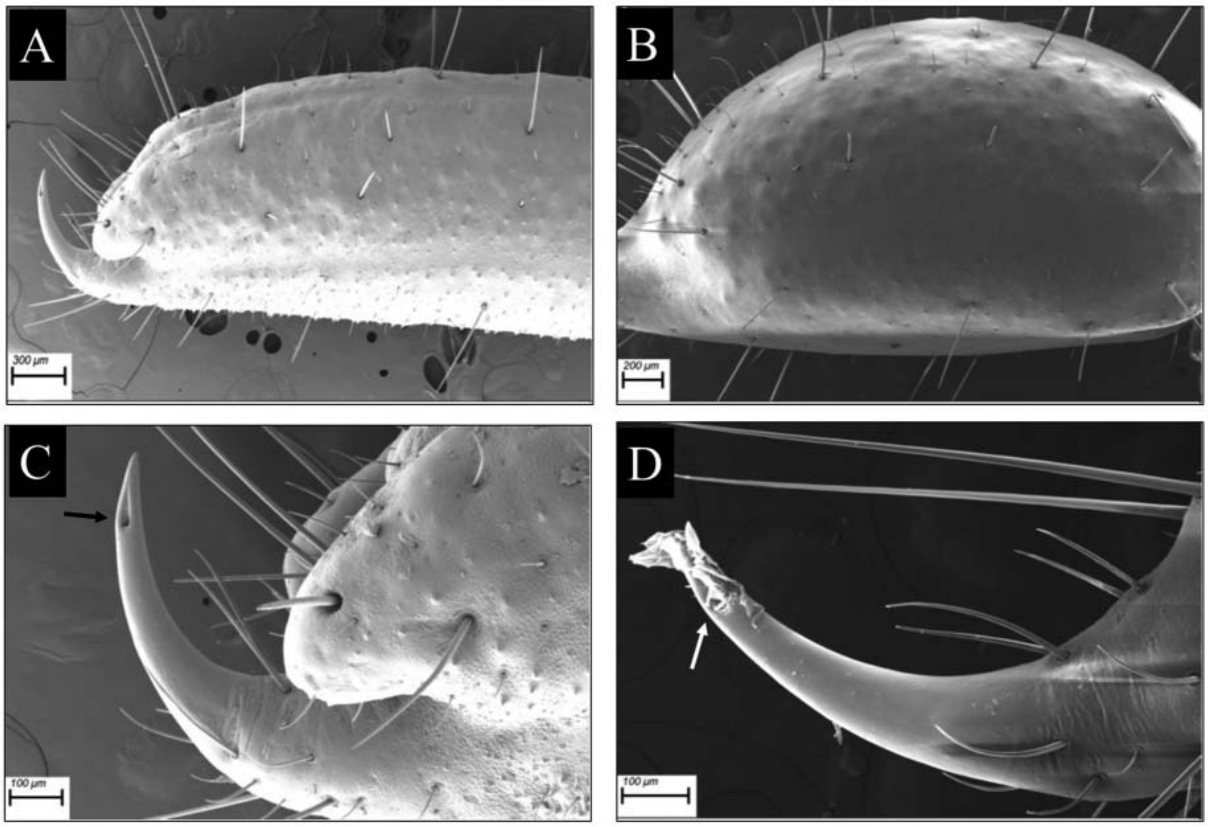

Fig. 11. *Hemiscorpius lepturus* Peters, 1861. A, C, E — male, B, D, F — female: A, B — proximal part of telson in lateral view; C, D — distal part of telson in lateral view (arrows show the venom gland openings on sting). Scale bars: A — 300 µm, B — 100 µm, C, D — 100 µm.

Рис. 11. *Hemiscorpius lepturus* Peters, 1861. A, C, E — самец; B, D, F — самка: A, B — проксимальная часть тельсона, латерально; C, D — дистальная часть тельсона, латерально (стрелками показаны отверстия ядовитых желез на жале). Масштаб: A — 300 мкм, B — 100 мкм, C, D — 100 мкм.

jovidae family, indicating that the number of sensilla is variable within taxonomic groups of various ranks. We also think that the constellation array found in both sexes should be functioned as a chemoreceptor (hygro-reception or/and thermo-reception) by its location on the pedipalp in the habitat.

Dorsal and ventral entire body surfaces of *H. lepturus* in both sexes are covered with wax openings (pores). The wax openings protect scorpion body surface from water loss, physical impacts and bacterial/fungal infections [Benli *et al*., 2013]. The waxes (lipids) are the principal waterproofing barrier on the cuticle surface associated with the epicuticle [Hadley, 1990]. *H. lepturus* species used in this present study were collected from hot and dry habitats in Iraq. A large number of wax openings and the wax secretion produced accordingly are used to prevent the body from drying out during climatic changes and to reduce water loss on the body surface.

The pectines are comb-like sensory structure, consisting of marginal lamellae, median lamellae, fulcra and pectinal teeth. These pectinal teeth are called as peg sensilla. These are also typical basiconic sensilla and each with slits at the ends. Peg sensilla provide the dual function of mechanoreception and contact chemoreception [Root, 1990; Gaffin, Brownell, 1997]. Bat-ear-like projections have been recorded for the first time on peg sensilla in a scorpion species, and we think that they may act as chemoreceptors in sensing moisture on the soil surface. The reason why these projections are longer in males than in females is thought to be likely because male individuals will detect female clue pheromones for mating.

Stigmata (spiracles) are the apparatus that open outward on the cuticle surface of the respiratory system. It was observed that the spiracles were closed in the examined species. We think that the reason for this is to prevent water loss in the dry and hot habitat of the scorpion and to prevent the entry of soil or other foreign objects into the respiratory system. On the other hand, it is also thought that it may have closed when it was placed in alcohol for fixation.

Scorpions have slit sensilla, being cuticular mechanoreceptors as proprioceptors detecting strain and substrate vibrations during movement. Barth & Stagl [1976] described three different slit sense organs (isolated slit

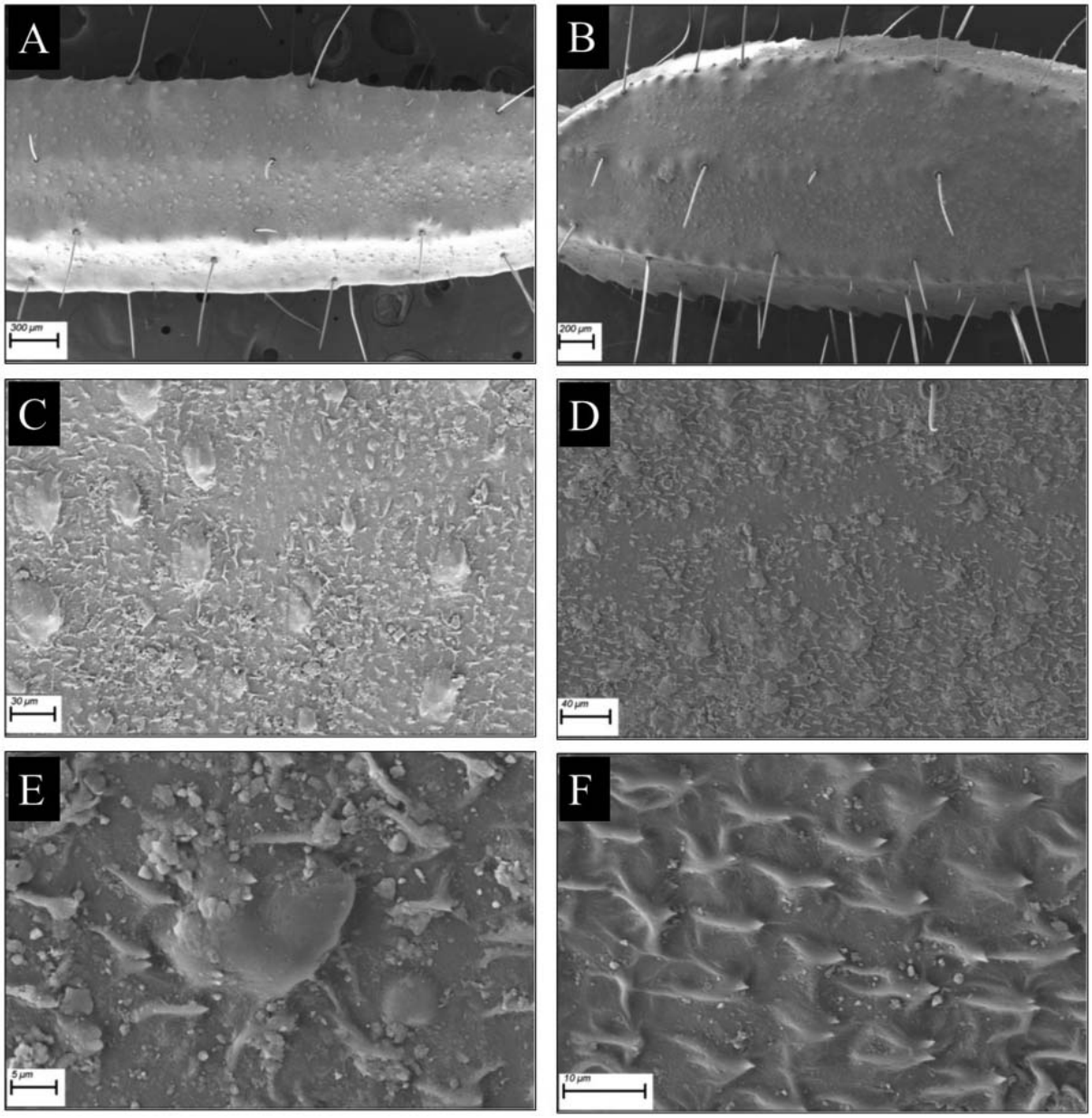

Fig. 12. *Hemiscorpius lepturus* Peters, 1861. A, C, E — male, B, D, F — female: A, B — 5th metasomal segment in lateral view; C, D — epicuticular protrusions on the 5th metasomal segment surface; E, F — microtrichia and tubercles in detail. Scale bars: A — 300 µm, B — 200 µm, C — 30 µm, D — 40 µm, E — 5 µm, F — 10 µm.

Рис. 12. *Hemiscorpius lepturus* Peters, 1861. A, C, E — самец, B, D, F — самка: A, B — 5-й сегмент метасомы, латерально; C, D — выросты эпикутикулы на поверхности 5-го сегмента метасомы; E, F — микротрихии и трубочки, детализировано. Масштаб: A — 300 мкм, B — 200 мкм, C — 30 мкм, D — 40 мкм, E — 5 мкм, F — 10 мкм.

sense organ, a group of single slits and lyriform or compound slit sense organs) in five arachnid orders Amblypygi, Araneae, Opiliones, Scorpiones, and Uropygi. They indicated that scorpions have isolated slit sensilla and a group of single slits, but not lyriform organs. In the present study, it is observed that the isolated single slit sensillum and in groups of two and three single slits in different segments of I–IV legs in *H. lepturus*. In addition, isolated slit sensillum is detected on the chelicera surfaces in both sexes of *H. lepturus* and it is thought that it may detect vibrations from prey to locate food

Conflict of Interest

The authors declare that they have no conflict of interest.

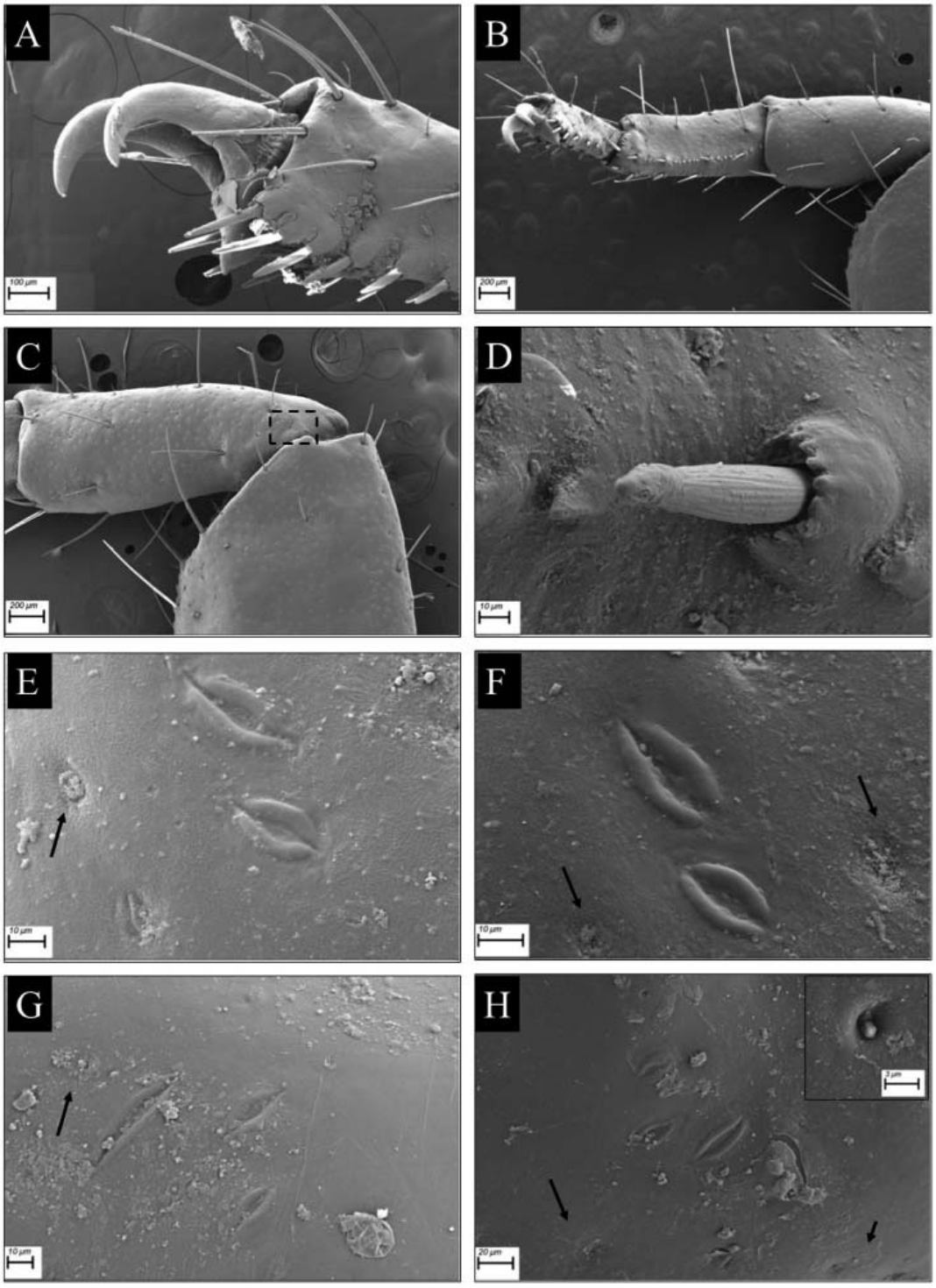

Fig. 13. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A — claws and telotarsus of 1st leg; B — claws, telotarsus, basitarsus, pretarsus and tibia of 1st leg; C — pretarsus and tibia of 1st leg (selected area with square shows the slit sensillum at E); D — sensilla chaetica on telotarsus of 1st leg; E, F — dual slit sensillum on distal part of tibia; G, H — triple slit sensillum on distal part of pretarsus (upper-right corner in H shows wax opening in detail). All arrows show wax openings. Scale bars: A — 100 µm, B, C — 200 µm, D, E, F, G — 10 µm, H — 20 µm.

Рис. 13. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H — самка: A — коготки и телотарзус 1-й пары ног; B — коготки, телотарзус, базитарзус, претарзус и голень 1-й пары ног; C — претарзус и голень 1-й пары ног (в квадрате щелевидная сенсилла, показана на E); D — хетовидная сенсилла на телотарзусе 1-й пары ног; E, F — двойные щелевидные сенсиллы в дистальной части голени; G, H — тройная щелевидная сенсилла в дистальной части претарзуса (в верхнем углу H показано отверстие восковой железы, детализировано). Все стрелки показывают отверстия восковых желез. Масштаб: A — 100 мкм, B, C — 200 мкм, D, E, F, G — 10 мкм, H — 20 мкм.

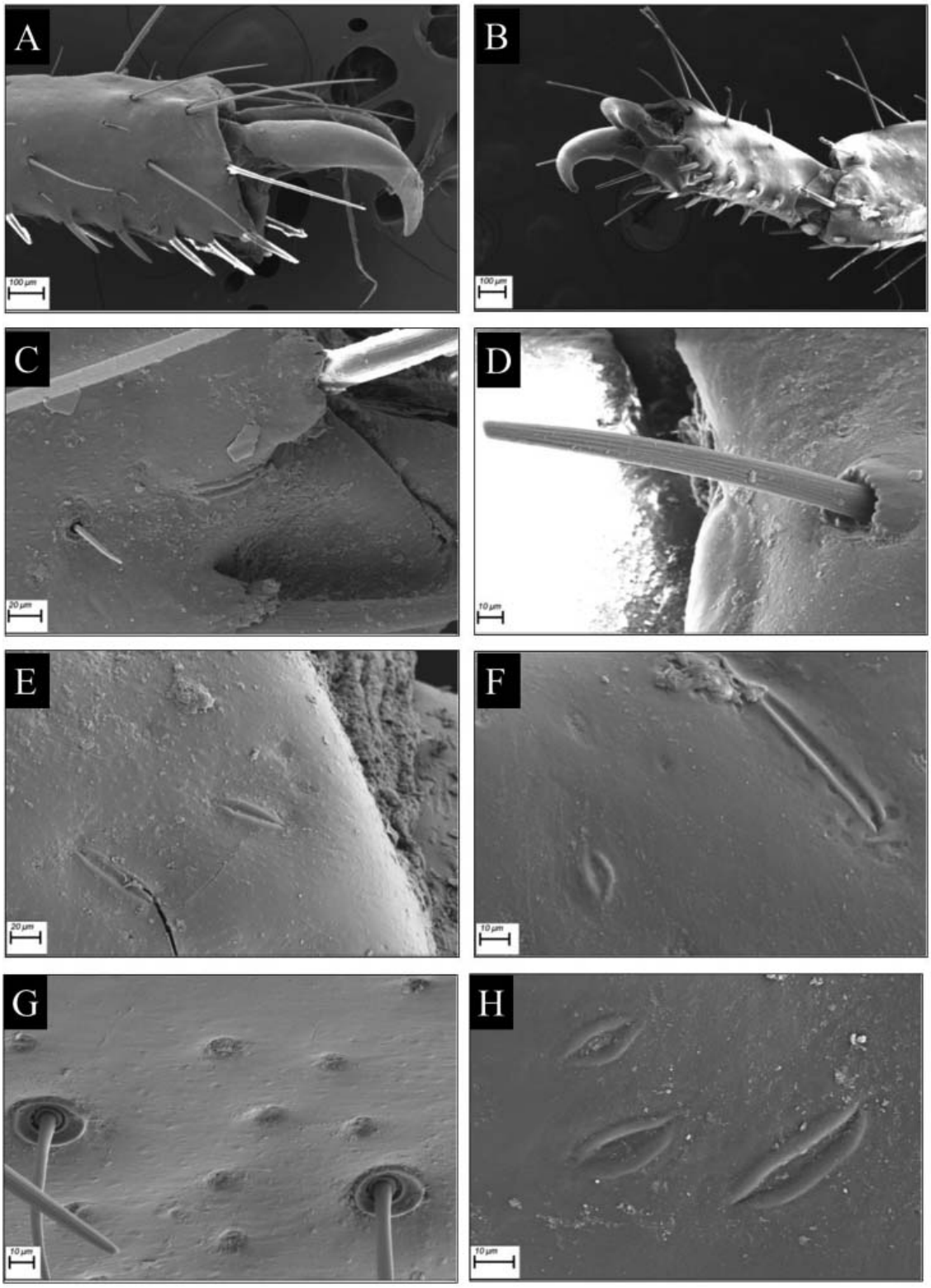

Fig. 14. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A, B — claws and telotarsus of 2nd leg; C — single slit sensillum on distal part of telotarsus; D — sensilla chaetica on basitarsus; E, F — dual slit sensillum on distal part of trochanter, G — wax openings; H — triple slit sensillum on distal part of tibia. Scale bars: A, B — 100 µm, C, E — 20 µm, D, F, G, H — 10 µm.

Рис. 14. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H — самка: A, B — коготки и телотарзус 2-й пары ног; C — единичная щелевидная сенсилла в дистальной части телотарзуса; D — хетовидная сенсилла на базитарзусе; E, F — двойная щелевидная сенсилла в дистальной части вертлуга, G — отверстия восковых желез; H — тройная щелевидная сенсилла в дистальной части голени. Масштаб: A, B — 100 мкм, C, E — 20 мкм, D, F, G, H — 10 мкм.

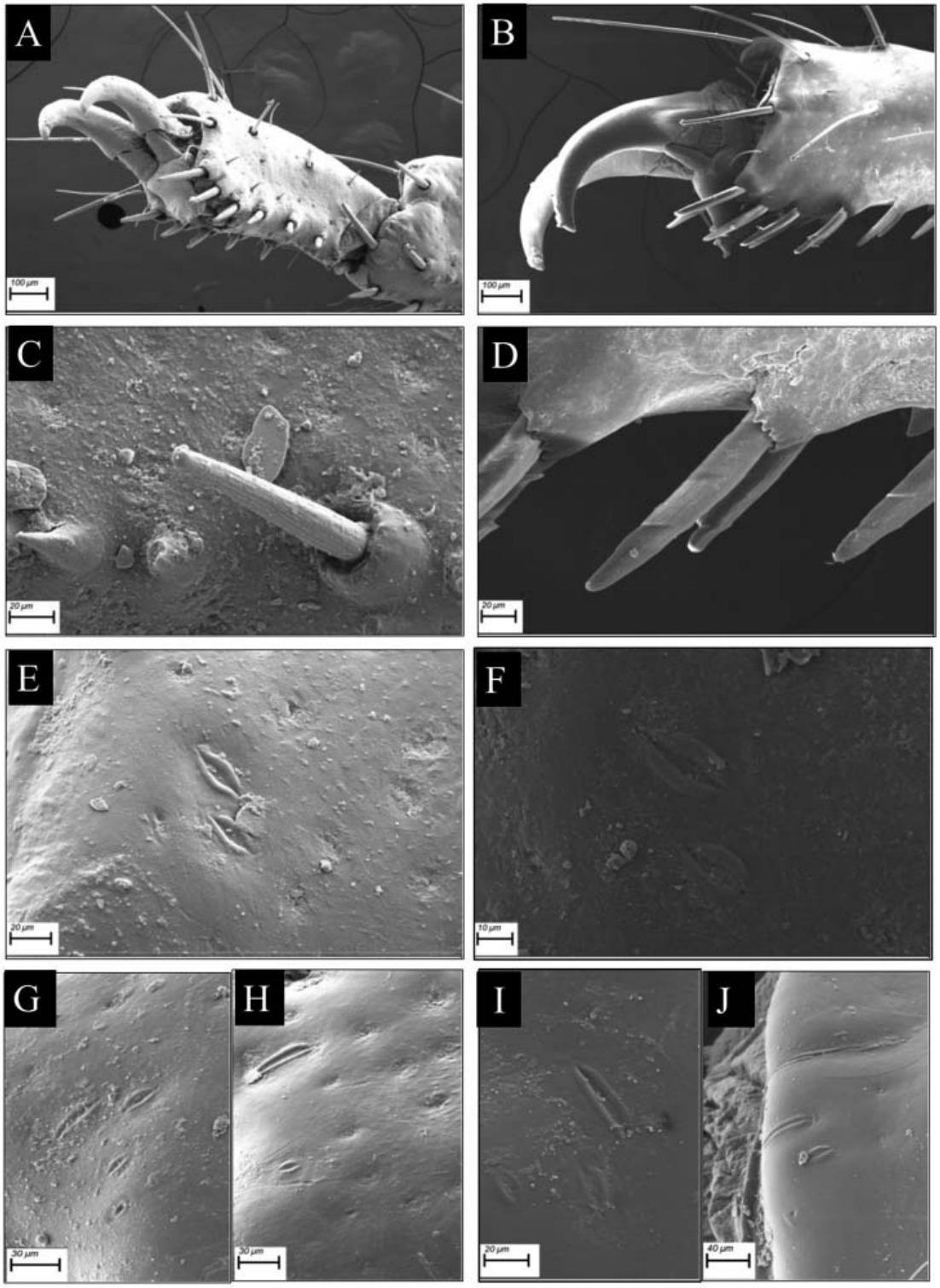

Fig. 15. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H–J — female: A, B — claws and telotarsus of 3rd leg; C — sensilla chaetica and cuticular protrusions on telotarsus of 3rd leg; D — sensilla chaetica on telotarsus of 3rd leg; E, F — dual slit sensillum on distal part of tibia; G, I — triple slit sensillum on distal part of pretarsus; H, J — dual slit sensillum on distal part of trochanter. Scale bars: A, B — 100 µm, C, D, E, I — 20 µm, G, H — 30 µm, F — 10 µm, J — 40 µm.

Рис. 15. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H–J — самка: A, B — коготки и телотарзус 3-й пары ног; C — хетовидные сенсиллы и выросты кутикулы на телотарзусе 3-й пары ног; D — хетовидная сенсилла на телотарзусе 3-й пары ног; E, F — двойная щелевидная сенсилла в дистальной части голени; G, I — тройная щелевидная сенсилла в дистальной части претарзуса; H, J — двойная щелевидная сенсилла в дистальной части вертлуга. Масштаб: A, B — 100 мкм, C, D, E, I — 20 мкм, G, H — 30 мкм, F — 10 мкм, J — 40 мкм.

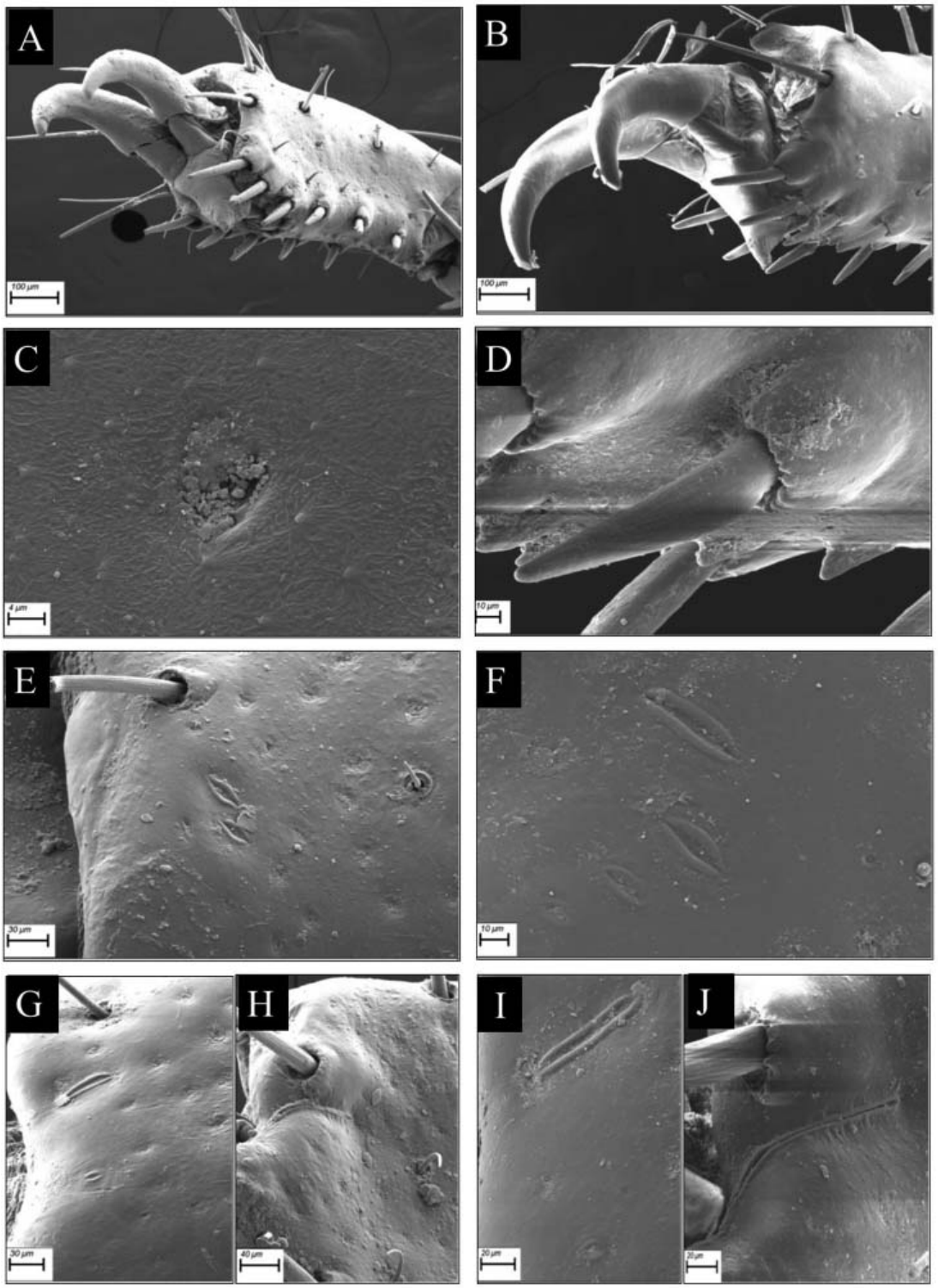

Fig. 16. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — male, B, D, F, H — female: A, B — claws and telotarsus of 4th leg; C — wax opening and epicuticular protrusions in detail on telotarsus of 4th leg; D — sensilla chaetica on telotarsus of 4th leg; E, F — triple slit sensillum on distal part of pretarsus; G, I — dual slit sensillum on distal part of tibia; H, J — single slit sensillum on distal part of basitarsus. Scale bars: A–B — 100 µm, C — 4 µm, D, F — 10 µm, E, G — 30 µm, H — 40 µm, I, J — 20 µm.

Рис. 16. *Hemiscorpius lepturus* Peters, 1861. A, C, E, G — самец, B, D, F, H — самка: A, B — коготки и телотарзус 4-й пары ног; C — отверстие восковой железы и выросты эпикутикулы на телотарзусе 4-й пары ног, детализировано; D — хетовидная сенсилла на телотарзусе 4-й пары ног; E, F — тройная щелевидная сенсилла в дистальной части претарзуса; G, I — двойная щелевидная сенсилла в дистальной части голени; H, J — единичная щелевидная сенсилла в дистальной части базитарзуса. Масштаб: A–B — 100 мкм, C — 4 мкм, D, F — 10 мкм, E, G — 30 мкм, H — 40 мкм, I, J — 20 мкм.

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