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Detailed Antennae Morphology and Sensilla Morphotype Diversity in *Sycanus annulicornis* Dhorm(Hemiptera: Reduviidae)

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Abstract

Sycanus annulicornis is a predatory reduviid that has potential as a biological control agent in agriculture, forestry, and increasingly on oil palm plantations. Despite their predatory potential, the study focuses on the morphological features of *S. annulicornis* is scant, particularly its detailed antennal morphology. The antennae play a crucial role in survival, particularly in detecting chemical and other environmental cues. This function, inferred from antennal sensilla, highlights the importance of studying the detailed features of *S. annulicornis* antennae. This study aims to identify and analyze sensilla distribution on the antennae of *S. annulicornis*. In this study, we observed the detailed morphology of *S. annulicornis* antennae and identified each sensillum morphotype using a scanning electron microscope (SEM). We observed four antennal segments, namely scape, pedicel, post-pedicel, and flagellum. We identified thirteen sensillum types based on variations in morphology, socket structure, and abundance. We organized these types into three spatial patterns across the antenna: basal segment concentrations, scape–pedicel junction associations, and flagellar distributions. The flagellum has the highest number and density of sensilla, indicating that the distal antennal segments function as the primary sensory region for receiving chemical stimuli. We also inferred the putative functions based on sensilla morphological features and distribution. These findings provide baseline information on the antennal sensory architecture of *S. annulicornis* and contribute to a better understanding of its sensory adaptations as a predatory insect.

1. Introduction

The Reduviidae is one of the most diverse families within the order Hemiptera, comprising over 6,600 species found worldwide (Weirauch, 2008). The Reduviidae, commonly known as predatory insects or assassin bugs, have a wide distribution, primarily concentrated in tropical and subtropical regions. Despite their high diversity, many species within this family remain poorly studied, particularly regarding their role as natural pest control agents (Lucas et al., 2016). *Sycanus annulicornis* is a member of the family Reduviidae within the order Hemiptera. *S. annulicornis* has attracted considerable attention as an effective biological pest control agent (polyphagous predator) across sectors such as agriculture, forestry, and oil palm plantations (Sahid, 2018; Sahid, 2019; Batubara, 2025). Several studies acknowledged the capability of *S. annulicornis* in delivering decent biological and ecological impacts as a biocontrol agent related to larval predation, broader prey preference, and enhanced ecosystem stability (Soesatrijo, 2023; Yuliadhi et al., 2021; Laksono, 2018; Mardiningsih, 2023). However, understanding the morphological profile of *S. annulicornis* is scant, particularly regarding body parts that influence predation ability, such as the antennae.

Commonly, antennae consist of a scape as the basal segment, a pedicel as the hinge joint, and a flagellum that exhibits a variety of shapes across insects (Elgar et al., 2018). Although most functional receptors in the antennae are commonly associated with olfaction, the antennal flagellum may contain more olfactory sensilla than the other segments (Ahmad et al., 2016). Rani and Wakamura (1993) reported that the scent of prey is first detected by receptors on the antennae, triggering an approach, this is also the natural behavior of *S. annulicornis* when hunting for prey. A study by Maneerat and Poopat (2021) identified several antennal behaviors during predation, which can be grouped into three main stages. (1) The antennae guide the proboscis towards the prey during the approach and capture stage as *Sycanus* approaches the prey, it extends its antennae towards the target as part of an initial response. (2) Antennal activities also occur during feeding, when the prey is completely motionless *Sycanus* sometimes releases it from its forelegs and raises its antennae. (3) After finishing feeding, *Sycanus* will rub its antennae against the comb on its forelegs. However, the specific functional role of each antennal segment in supporting these distinct behavioral stages has not yet been thoroughly detailed. This behavior is similar to that of other Reduviidae, namely *Endochus albomaculatus* Stål, *Epidaus bicolor* Distant, *Euagoras plagiatus* Burmeister, *Irantha armipes* Stål, *Panthous bimaculatus* Distant, and *Sphedanolestes signatus* Distant (Srikumar et al., 2014). This highlights the importance of antennation in predatory behavior and underscores the need to investigate its underlying antennal anatomy and ultrastructure (Sahid, 2019; Batubara, 2025).

Antennae can detect a wide variety of environmental signals, as they are multimodal sensory organs equipped with specialized receptors to detect diverse environmental stimuli, such as changes in temperature, volatile compounds, humidity, and mechanical vibrations simultaneously (Wikantyoso et al., 2022). The fundamental cuticular sensory unit of an insect antenna is the sensillum, which may occur externally as a hair-, bristle-, peg-, pit-, or dome-like structure. The morphology and distribution of antennal sensilla may vary among taxa, antennal segments, sexes, and developmental stages, making these characteristics potentially informative for morphological and comparative studies. Nevertheless, the antennal sensilla of *Sycanus annulicornis* remain insufficiently documented. Accordingly, this study aimed to elucidate the detailed anatomy of *S. annulicornis* antennae. Furthermore, this manuscript identifies, characterizes, and describes the morphological variation and distribution of sensilla on the antennae of *S. annulicornis* using scanning electron microscopy. These findings provide fundamental information on the detailed structure of *S. annulicornis* antennae and a baseline inventory of external cuticular characteristics and the spatial organization of antennal sensillum morphotypes in this species, supporting future comparative investigations within *Sycanus*, Harpactorinae, and Reduviidae, as well as subsequent ultrastructural, electrophysiological, and behavioral studies.

2. Materials and methods

Sample collection

The *Sycanus annulicornis* specimens were collected (Fig. 1). The specimens were collected in Bogor, West Java, Indonesia, at coordinates 6.6328643°S, 106.7509683°E. The specimens were preserved in 95% ethanol. Six imago specimens were examined, comprising three males and three females, with the right and left antennae removed from each specimen, resulting in 12 antennae for SEM examination. The antennae were carefully separated using a sharp micro-knife or scissors to maintain the integrity of the antennal structure, with the aid of a stereo microscope (Olympus SZ2-ILST, Tokyo, Japan). Subsequently, the separated antennae were further processed for analysis using a Scanning Electron Microscope (SEM JEOL JSM-IT200 + EDS, Tokyo, Japan).

Scanning electron microscopy preparation

Preparation begins with gradual rehydration to restore the specimen from 95% alcohol storage to the appropriate conditions. Fixation is then carried out with 2.5% glutaraldehyde to preserve cellular structure, followed by gradual dehydration using a series of alcohols (50%, 70%, 85%, 95% and absolute alcohol), then t-butanol. Afterward, the antennae were cut into two sections at the junction between the scape and pedicel. The antennae were mounted on SEM stubs using conductive carbon adhesive tape and coated with a conductive metal (gold) using an ion coater (Eiko IB-2). SEM examination was performed using a JEOL JSM-IT200 scanning electron microscope (SEM), with parameters set such as an acceleration voltage of 5 kV. Images were captured at various magnifications ranging from 400 to 12,000 times to document the type, distribution, density and structure of the sensilla on the specimen.

Antennae and sensilla characterization

The structure of the antennae is described, and the identification and structural characterization of sensilla were carried out with reference to Altner and Prillinger (1980), Altner et al. (1977), Hansen and Heumann (1971), Altner and Loftus (1985), and Wikantyoso et al. (2022), in which sensilla are classified into specific types based on the presence or absence of pores, a striated or smooth surface, and a flexible or rigid socket at the base of the sensilla. The distribution of sensilla on the surface of the antennae of *S. annulicornis* was identified and counted on each antenna segment based on the cuticle, morphology, and structure of the sensilla. We measured and summarised the length and number of sensilla on each segment. To represent the total density across all antennal segments, this research quantified the number of different sensilla types per unit area. Insects exhibit considerable diversity in antennal sensilla morphology, reflected in variations in shape, size, surface sculpture, apical structure, socket configuration, and spatial distribution (Ren et al., 2023). Based on these morphological characteristics, antennal sensilla are commonly classified into groups such as sensilla trichodea, chaetica, basiconica, coeloconica, and campaniformia, which may be further divided into subtypes or morphotypes.

3. Results

Antennae gross structure

The shape of the antennae of *S. annulicornis* represents the geniculate-filiform type of antennae (Fig. 1). It consists of a scape, a pedicel, a post-pedicel, and a flagellum as the longest segment in the antennae. The scape is long and connects to the pedicel, forming an angled joint (Fig. 2). This angled joint between the scape and pedicel is supported by the structure at the rear end of the scape that is sclerotized and hardened. The dorsal part of the scape's rear end overhangs the ventral part, by which creating an angled joint for the pedicel.

Male and female *S. annulicornis* antennae have the same structure, consisting of four cylindrical segments called antennomeres (Fig. 1). Across all four segments, male antennae averaged 17.10 ± 1.26 mm and female antennae averaged 16.71 ± 1.65 mm. Overall, antenomere size varied among individuals. In male *S. annulicornis*, the mean segment lengths were scape (5.85 ± 0.437 mm), pedicel (2.09 ± 0.304 mm), post-pedicel (1.24 ± 0.112 mm), and flagellum (7.91 ± 0.990 mm). In female *S. annulicornis*, the antenna segments measured scape (6.06 ± 0.461 mm), pedicel (2.00 ± 0.169 mm), post-pedicel (1.26 ± 0.140 mm), and flagellum (7.39 ± 1.429 mm). No differences were detected between male and female sensilla. The observations reveal no striking differences between males and females in this species.

Characteristics of sensilla

Based on the morphological variations observed, we identified thirteen distinct types of antennal sensilla (Type I to Type XIII), as shown in Table 1 and illustrated in Fig. 3. Each type has distinct morphological characteristics, such as growth orientation (leaning peg or perpendicular peg), surface texture (smooth or with longitudinal grooves), and socket type.

Table 1

Types, distribution, and lengths of sensilla observed in *Sycanus annulicornis*. Data on cuticle characteristics, distribution, number found in a single antenna an of sensilla: Sc: Scape, Pd: Pedicel, Pp: post-pedicel, Fl: Flagellum, n: number of sensilla in the measurement.

Type	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Characteristics	Peg	Peg	Peg	Peg	Peg	Peg	Peg	Peg	Peg	Peg	Peg in pit
	Leaning peg	Leaning peg	Leaning peg	Leaning peg	Leaning peg	Perpendicular peg	Leaning peg	Leaning peg	Leaning peg	Leaning peg	-
	Smooth	Longitudinal Groves	Smooth	Smooth	Longitudinal Groves	Smooth	Uniporous	Pores	Smooth	Pores	smoot
	Short peg	Long peg	Short peg	Long peg	Long peg	Long peg	Long peg	Short peg	Short peg	Long peg	
	Flexible socket	Flexible socket	Flexible socket	Flexible socket	Flexible socket	Flexible socket	Wringkle socket	Stiff socket	Stiff socket	Stiff socket	-
Distribution	Sc, Pd, Pp	Sc, Pd	Sc, Pd	Sc, Pd	Sc, Pd, Pp, Fl	Pd	Junction	Pp, Fl	Pp	Pp, Fl	Sc, Pd Pp, Fl
Total Sampels (n)	110	24	52	85	437	6	1	161	4	3598	7
Length range (μm) (n = 15)	16,13 ± 0,694	46,84 ± 2,148	10,61 ± 0,176	61,874 ± 2,62	89,94–123,92	213,1 ± 12,030	25,65 ± 3,244	11,01–13,80	9,849 ± 0,295	61,76 ± 0,901	0,78–1,42

In terms of numbers, Type X is the most dominant sensilla type, with 3,598 samples and an average length of 62.533 µm. In contrast, Type VI has the longest sensilla, at 198.900 µm, although it was found only on the pedicel. Most sensilla types were found on scape to post-pedicel segments, though some were more widely distributed, such as Type IV and Type V. Sensilla lengths varied considerably, from the smallest, such as Type XI (0.947 µm), to the longest, such as Type VI.

Type I – sensilla: the first type of sensilla we encountered on the scape (the first segment of the antenna) (Fig. 4a). These sensilla are relatively small, measuring approximately 15.588 µm, with a flexible socket and a smooth surface. This sensillum has a rounded tip with a slight curvature just before the tip. It is predominantly found on the scape and pedicel of the antennae of *S. annulicornis* (Fig. 8a).

Type II – sensilla: unlike the previous type, these sensilla have a more distinct structure, with longitudinal grooves (Fig. 4c). These sensilla have a pointed, smooth tip (the longitudinal grooves do not extend to the tip), as does the base. They have a flexible socket, with a gap between the socket and the sensillum that is not entirely empty/fairly tight. These sensilla are predominantly found on the first antennal segment (Fig. 8a), with a mean length of 46,837 µm.

Type III – sensilla: Type 3 sensilla are relatively small, with a mean length of 10.61 µm (Fig. 4b). These sensilla are oval with rounded tips. They have a smooth surface without pores and a flexible socket. These sensilla are commonly found on the scape but also frequently on the antennae, though in a different arrangement (Fig. 8a).

Type IV – sensilla: Type 4 sensilla are large, with a smooth surface, a pointed tip, and no pores (Fig. 5a). These sensilla have a mean length of 61.874 µm. Given their considerable size, these sensilla possess a flexible socket that protrudes slightly inwards, with a fairly large gap. These sensilla are found on the scape and pedicel (Fig. 8a).

Type V – sensilla: these sensilla have the largest diameter of all types and the widest distribution, as they are found on every segment of the antenna (Fig. 8). They have a length ranging from 112.84 µm. Because of their considerable size, they have a base that protrudes slightly outward with a flexible socket. This sensillum has a surface texture featuring longitudinal grooves with a pointed tip (Fig. 5b).

Type VI sensilla: this sensillum was only recently discovered on the pedicel/second antennomere segment (Fig. 8b). Its structure differs significantly from sensilla on other segments. Type 6 sensilla stand perpendicular to the antenna, unlike the other sensilla. This sensilla is also the longest, measuring approximately 221.632 µm, with a smooth surface. It has a pointed tip and a flexible socket that appears to consist of two layers, shaped like a dome and protected by a collar-like structure (Fig. 5c).

Type VII – sensilla: this sensilla has a unique distribution, as it is found only at the junction between the scape and the pedicel (Fig. 8a). This sensilla has a smooth surface but features a unipore at both the tip and base. The socket of Type 7 sensilla is flexible, concave, and conical. This sensilla measures approximately 25.648 µm. Occasionally, this sensilla is found compressed by the antenna (Fig. 4d).

Type VIII – sensilla: these sensilla were only recently discovered on the post-pedicel and flagellum, a peg attaches them directly to the antenna, limiting their range of movement (Fig. 8c and 8d). These sensilla are elongated, following the direction of the antenna. The pointed tip is accompanied by nanopores along its shaft, measuring 12.813 µm in length (Fig. 6a).

Type IX – sensilla: unlike most sensilla types, sensilla type 9 has a limited distribution. These sensilla occur only at the tip of the third antennal segment of *S. annulicornis* (Fig. 8c). They lack pores along their shaft. However, unlike most non-porous sensilla, these sensilla also lack a flexible socket. These sensilla appear to be compressed by the antenna. Their length is approximately 9.848 µm (Fig. 6b).

Type X – sensilla: Type 10 sensilla are the most numerous sensilla found along the antenna of *S. annulicornis*. They begin to appear in the post-pedicel region with high density (Fig. 8c and 8d). This sensilla has a non-flexible socket with a pointed tip. The shaft of this sensilla is perforated with pores so small they are only visible at 6000x magnification. This sensilla has a shaft length of approximately 61.764 µm (Fig. 6c).

Type XI – sensilla: These sensilla are small, with a shaft protruding to the surface measuring approximately 0.78–2.48 µm (Fig. 7a). They are accompanied by a flexible socket with irregularly shaped or protruding edges. These sensilla have a smooth surface without any pores. These sensilla are distributed across all four segments but are difficult to detect because of their small size relative to other sensilla.

Type XII sensilla are small and similar in shape to type 11 sensilla. They are also found scattered across all antennomers (Fig. 7b). They measure approximately 2.00–2.48 µm. The difference between type 12 and type 11 sensilla lies in their edges, which are concave.

Type XIII – sensilla: these sensilla are small and appear as a cluster of hairs within a single socket (Fig. 7c). They protrude slightly, with a cuticle size of approximately 1 µm and a socket diameter of approximately 1.48–1.98 µm. These sensilla are distributed across all antennomers but are difficult to detect.

Plate-type – Concave disc-like sensilla: A concave oval structure embedded within the antenna. These sensilla lack a stalk protruding from the surface (Fig. 7c). Plate-type sensilla are located in parts of the antenna capable of deformation, particularly near the junction.

Distribution of sensilla

The distribution of sensilla on the antennae of *S. annulicornis* reveals variation in the types of sensilla found on each segment (Fig. 8). Type I sensilla are distributed from the scape to the post-pedicel. Types II and III are found only on the scape. Type IV sensilla are found on the scape and pedicel, whilst type V sensilla are present on every segment, showing the highest abundance of occurrences compared to other sensilla with flexible sockets. Type VI sensilla occur only on the pedicel in small numbers, as do type VII sensilla, which are present only at the junction between the scape and pedicel. Types VIII, IX, and X are only found on the post-pedicel (segment three), where all three sensilla possess rigid/non-flexible sockets. However, unlike types VIII and IX, type IX

sensilla are thought to function as mechanoreceptors. Types XI, XII, and XIII are difficult to detect due to their small size, yet they are still present in all four segments. Overall, segment four (the flagellum) has the highest number of sensilla among the segments.

The flagellum segment has the highest number of sensilla than the other segments, with 3,377 sensilla of various types (Fig. 5A). The post-pedicel segment also exhibits a fairly significant number, although far fewer than the flagellum, at around 488 sensilla. The pedicel segment has slightly fewer sensilla, around 345. Meanwhile, the scape has the fewest sensilla, with only around 287. The density of sensilla in each antenna segment is shown in Fig. 5B. The highest sensilla density is recorded in the flagellum segment, at around 0.0043 sensilla per square micrometer. The post-pedicel also exhibits a fairly high density, at around 0.0032 sensilla per square micrometer, whilst the pedicel has a density of 0.0020 sensilla per square micrometer. The scape exhibits the lowest density, at 0.0005 sensilla per square micrometer, reflecting the few sensilla in this segment (Fig. 9e).

4. Discussion

Based on our observations, we detected no clear morphological differences in antennal sensilla between male and female *S. annulicornis*. This finding aligns with broader observations in other predatory or true bugs, such as Gonzaga-Segura et al. (2013) on *Leptoglossus zonatus*, which similarly reported no sexual dimorphism in antennal sensory organs. They hypothesized that gregariousness in both sexes depends on having the same sensilla to perceive conspecific aggregation pheromones. In other insects such as *Nezara viridula* (Linnaeus, 1758), *Arma chinensis* Fallou, 1881, *Plautia crossota* (Dallas, 1851), and *Halyomorpha halys* (Stål, 1855), males and females also show no significant differences in sensilla type, length, or total number. In this study, the sensory organs of both sexes showed no significant differences, with all sensilla types present in each sex and a comparable distribution pattern.

Geniculate antennae and functional impact

A fossil of the Mecoptera group, which is indicated to feed on pollinating drops of gymnosperm host plants, possessed similar pectinate antennae type (Gao et al., 2016). While several insects with geniculate insect may have a broader range of food sources which are located at unease and hidden locations, such as *Pediobius imbreus*, which parasitizes the larva of *Javeta pallida* mining inside *Phoenix sylvestris* folded leaves (Shameem et al., 2016). Filiform antennae type, likewise, is also possessed by insect who has inconspicuous prey, such as *Arotes amoenus*, which feeds on the liquid of the Cerambycid larvae inside the wood (Brues., 1927). In our study, *S. annulicornis* has both types of long, slender geniculate-filiform antennae. This pair of antennae ease their job in finding the liquid of their larval prey and pick the right oviposition spot located under the leaves, while they maintain their body on the upper side of the substrate.

Geniculate-filiform antennae can offer several advantages in prey hunting; this combination provides functional benefits during prey hunting by facilitating directional movement of the antennae and expanding the sensory surface area available for environmental exploration. These potential advantages stem from the combination of the two morphological characteristics of the antennae. The geniculate articulation provides greater flexibility in antenna orientation and movement, whilst the thread-like (filiform) shape of the flagellum provides an expanded sensory surface area due to its slender and elongated form. This swinging movement of the antennae has previously been observed in the assassin millipede (Wang et al., 2020). Previous research has shown that chemical stimuli from live prey can enhance the feeding response of the assassin millipede (Haridass & Ananthakrishnan, 1980).

Spatial Distribution of Antennal Sensillum Morphotypes

The antennal sensillum morphotypes of *S. annulicornis* exhibited a spatially heterogeneous distribution across the four antennomeres: the scape, pedicel, post-pedicel, and flagellum. Some morphotypes were restricted to particular segments or intersegmental regions, whereas others occurred throughout the antenna. This pattern indicates morphological regionalization of the antennal surface rather than a uniform sensillar arrangement. The basal antennomeres were characterized mainly by relatively large hair- or bristle-like morphotypes with distinct sockets, whereas the flagellar antennomeres contained a greater representation of short peg-like and putatively multiporous morphotypes. In several Ectrichodiinae, sensilla chaetica occur on the pedicel, post-pedicel, and flagellum, although their abundance and dimensions vary among species (Zha et al., 2023).

The pedicel was distinguished by the presence of Type VI, which was not observed on the other antennomeres. Its exceptional length, perpendicular orientation, and specialized socket support its tentative correspondence with a trichobothrium. Pedicellar restriction is consistent with the pattern reported in other Reduviidae. Trichobothria in the examined Ectrichodiinae were rare and restricted to the pedicel (Zha et al., 2023), while those of *Rhodnius brethesi* formed a row on the dorsal surface of the second antennal segment (Freitas et al., 2020). The consistent association of this morphology with the pedicel across several reduviid lineages strengthens the interpretation of Type VI as a trichobothrium-like structure. Type VII exhibited an even more restricted distribution because it occurred only at the scape–pedicel junction. Its location and occasional compression by the adjacent cuticle indicate a close morphological association with the intersegmental articulation. This pattern is comparable to that of Böhm's bristles, which are typically located around the head–scape and scape–pedicel junction and may be physically displaced by the movement of the junction membrane (McCarter & Loudon, 2025).

We observed a different sensillar pattern on the flagellar antennomeres. Type VIII first appeared beyond the pedicel and was associated primarily with the post-pedicel and flagellum. Type X similarly occurred from the post-pedicellar region towards the distal antenna and showed the highest apparent abundance among the recorded morphotypes. Its concentration on the flagellar surface resembles the distribution of long multiporous trichoid sensilla reported in other Heteroptera. In *Graphosoma italicum*, trichoid and basiconic sensilla are concentrated mainly on the flagellar antennomeres, whereas the scape and pedicel are dominated by chaetic forms (Brożek et al., 2024). A comparable distal concentration of trichoid, basiconic, and coeloconic sensilla has also been reported in R. brethesi, in which the third and fourth antennal segments contain a greater variety of sensillar forms than the pedicel (Freitas et al., 2020).

These comparisons indicate that the basal-to-distal change in sensillum composition observed in *S. annulicornis* broadly matches patterns documented in other Heteroptera.

Type IX showed the most localized distribution among the flagellar morphotypes because it was observed only at the distal end of the third antennomere or basiflagellomere. This restricted distribution suggests that its presence is associated with a specific structural region rather than the flagellum's general surface. In contrast to the regionally restricted morphotypes, Types XI, XII, and XIII were distributed across all four antennomeres. Their widespread occurrence suggests that these minute structures are not confined to a particular antennal region. However, because they measure only approximately 0.8–2.5 μm and are difficult to distinguish from cuticular ornamentation, their observed abundance may be strongly affected by magnification, image resolution, coating thickness, and specimen orientation. Therefore, interpret comparisons involving these morphotypes cautiously. Confirming that Types XI–XIII are true sensilla rather than non-innervated microstructures would also be necessary before comparing their distribution directly with that of the larger sensillar morphotypes. Overall, the antennal sensilla of *S. annulicornis* fall into three broad spatial patterns: morphotypes concentrated on the basal antennomeres, morphotypes specifically associated with the scape–pedicel junction, and morphotypes predominantly distributed on the flagellar antennomeres. Types V and XI–XIII are widely distributed, whereas Types II, VI, VII, and IX show relatively restricted distributions. These findings demonstrate that the morphological diversity of sensilla in *S. annulicornis* is accompanied by distinct spatial organization along the antenna.

Comparative Sensilla Morphology Variation among Heteroptera and Other Predatory Insects

The antennal sensillar assemblage of *Sycanus annulicornis* comprises at least thirteen externally distinguishable shafted morphotypes and one plate-like structure. These comparisons indicate that *S. annulicornis* shares several recurring sensillar forms with other heteropterans. Nevertheless, the proposed correspondences should be regarded as morphological similarities rather than confirmation of homology or sensory function. Within Reduviidae, other assassin bugs have shown comparable sensillar forms and segment-specific distribution patterns. In several species of Ectrichodiinae, sensilla chaetica were characterized by elongated shafts, longitudinal grooves, pointed tips, and articulated sockets, whereas exceptionally long trichobothria occurred exclusively on the pedicel (Zha et al., 2023). These characteristics closely resemble Types II and V and the pedicel-restricted Type VI of *S. annulicornis*. A differentiated proximal–distal pattern has also been reported in the blood-feeding reduviid *Rhodnius brethesi*, in which bristle-like sensilla and trichobothria were mainly associated with the pedicel, while basiconic, coeloconic, and trichoid sensilla were concentrated on the flagellomeres (Freitas et al., 2020). Despite differences in feeding biology between predatory Harpactorinae and blood-feeding Triatominae, the recurrence of similar external forms and their separation between proximal and distal antennomeres suggests that part of the sensillar organization observed in *S. annulicornis* may represent a general reduviid pattern rather than a feature exclusively associated with predation. Similar patterns are also found in other Heteroptera. In the predatory flower bugs *Orius maxidentex* and *O. minutus*, four principal categories sensilla trichodea, chaetica, basiconica, and campaniformia were recognized, with trichoid and chaetic sensilla further separated into subtypes (Liu et al., 2025). Studies of Pentatomidae have likewise shown that most sensilla are concentrated on the flagellar segments rather than on the scape and pedicel. This general pattern is comparable to the high density of Type X and the occurrence of Types VIII and IX in the distal antennal region of *S. annulicornis*. In a comparison of predatory and *phytophagous pentatomids*, six sensillar categories were recorded. Sensilla coeloconica occurred only in the predatory species examined, whereas trichoid, basiconic, and chaetic sensilla were more numerous in the phytophagous species (Ahmad et al., 2016). These findings demonstrate that feeding guild may coincide with differences in sensillar composition, but they also show that predatory insects do not necessarily possess a greater overall abundance or diversity of sensilla.

More accurately, *S. annulicornis* exhibits a high degree of externally distinguishable morphological variation under the classification criteria applied in this study. Comparisons with predatory insects from other orders further indicate that most broad sensillar forms are not exclusive to predatory Heteroptera. Nine sensillar categories, including chaetica, trichoidea, basiconica, Böhm's bristles, campaniformia, placoidea, coeloconica, sporangia, and styloconica, have been reported in the predatory ladybird beetles *Menochilus sexmaculatus* and *Propylea dissecta*, with most sensilla concentrated on the terminal flagellomere (Pervez et al., 2020). In the predatory mantis *Creobroter nebulosa*, seven principal types and eleven subtypes were identified, including chaetic, trichoid, basiconic, coeloconic, campaniform, grooved-peg sensilla, and Böhm's bristles (Wang et al., 2024). The occurrence of comparable morphological categories in distantly related predatory insects suggests that these forms represent widespread components of the insect antennal sensory system rather than morphological specializations that can be attributed to predation alone. Differences in their number and distribution may also be influenced by phylogenetic history, antennal architecture, sex, habitat, and the criteria used to distinguish sensillar subtypes.

Overall, the sensillar pattern of *S. annulicornis* combines broadly conserved insect sensillar forms with fine-scale morphological variations and segment-specific distributions. Comparisons with closely related Reduviidae are therefore more informative for evaluating taxonomic or lineage-associated variation, whereas comparisons with predators from other orders provide broader ecological context but weaker evidence of adaptation to predation. Future comparative studies should prioritize species of *Sycanus*, other Harpactorinae, and closely related non-predatory Heteroptera using standardized morphological criteria, magnification, sampling area, and morphometric measurements. Under the current SEM-based evidence, the thirteen morphotypes are most appropriately interpreted as a detailed baseline of external sensillar diversity rather than direct indicators of sensory function or predator-specific adaptation. However, similarities or differences in external appearance do not necessarily demonstrate equivalent or distinct sensory functions. Therefore, studies based solely on scanning electron microscopy should primarily interpret these structures in terms of morphological diversity and spatial organization rather than assign definitive physiological roles.

4. Conclusion

The morphology of the sensory organs on the antennae of *S. annulicornis* is consistent in both sexes. This study reveals that the antennae of *S. annulicornis* possess a variety of sensilla types with differing distribution patterns along the scape, pedicel, post-pedicel and flagellum. A total of thirteen sensilla types have been identified, differing in terms of morphology, socket structure and number, and can be grouped into three main spatial patterns: a morphotype concentrated on the basal antenna segments, a morphotype specifically associated with the scape–pedicel junction, and a morphotype predominantly found on the flagellum segments. The flagellum exhibits the highest number and density of sensilla, indicating that the distal antennae segments function as the primary sensory region of the antennae for receiving chemical stimuli. This diversity of sensilla highlights the importance of the antennae as sensory organs in Hemiptera, aiding their orientation within the environment.

Declarations

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Author Contribution

Author Contribution StatementMuhammad Bayu Setiaji. Wrote the main manuscript, data curation, formal analysis, resources; Berry Juliandi. supervision, conceptualization, investigation; Sri Utami. supervision, write the main manuscript, conceptualization; Dewi Sartiami. supervision, conceptualization, investigation; Bramantyo Wikantyoso. visualization, wrote the main manuscript, validation, methodology; Dedi Hutapea. software, formal analysis, methodology; Hery Widyanto. software, formal analysis, methodology; Nida Nur Rahmah. data curation, formal analysis, resources; Didi Tarmadi. supervision, conceptualization, formal analysis; Andhika Yudha Prawira. supervision, conceptualization, validation.All authors reviewed the manuscript.

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Figures

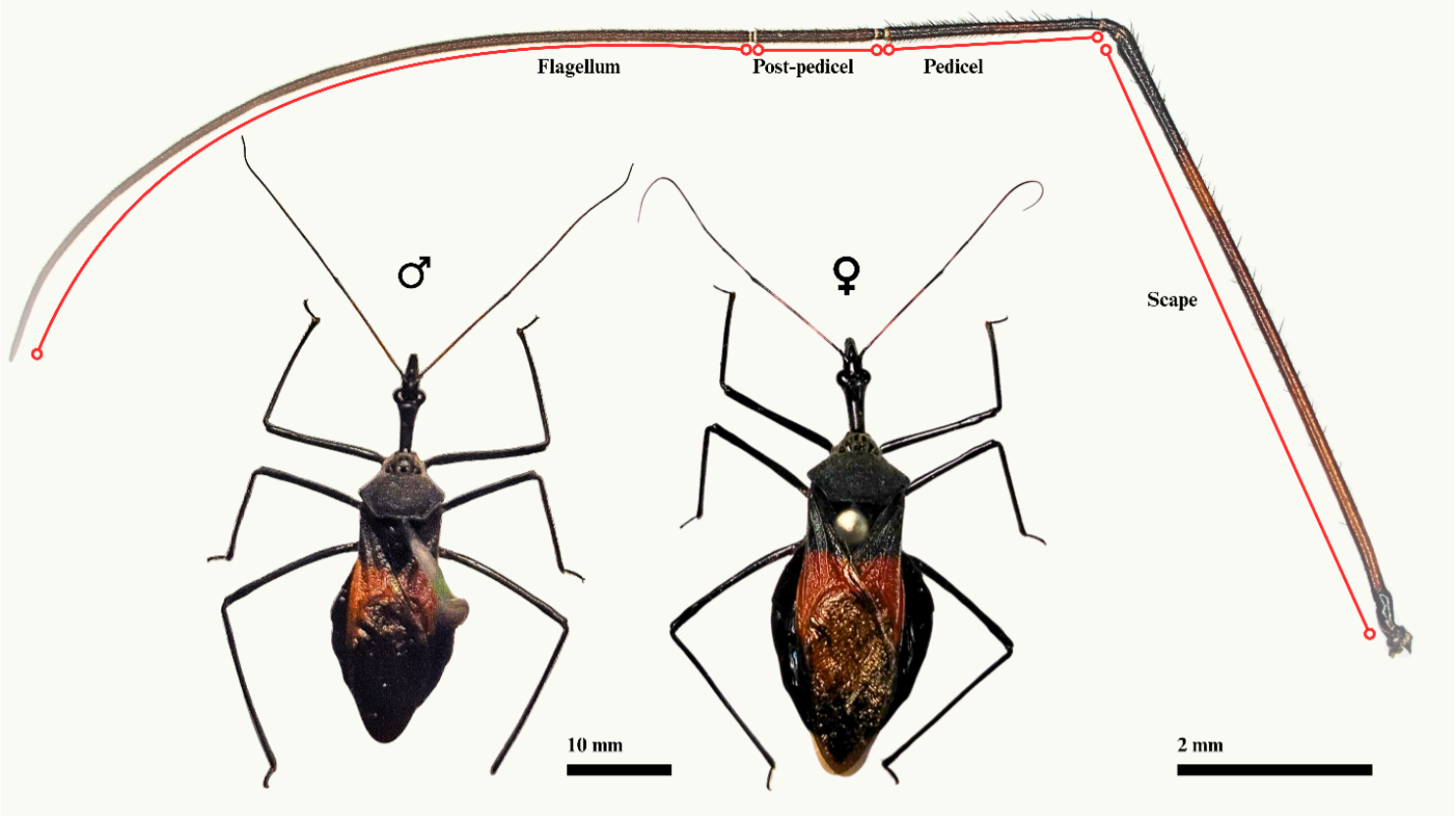

Figure 1

Male and female species of *Sycanus annulicornis*. Antennomeres of *S. annulicornis* examined under a light microscope. a: scape, b: pedicel, c: post-pedicel, d: flagellum.

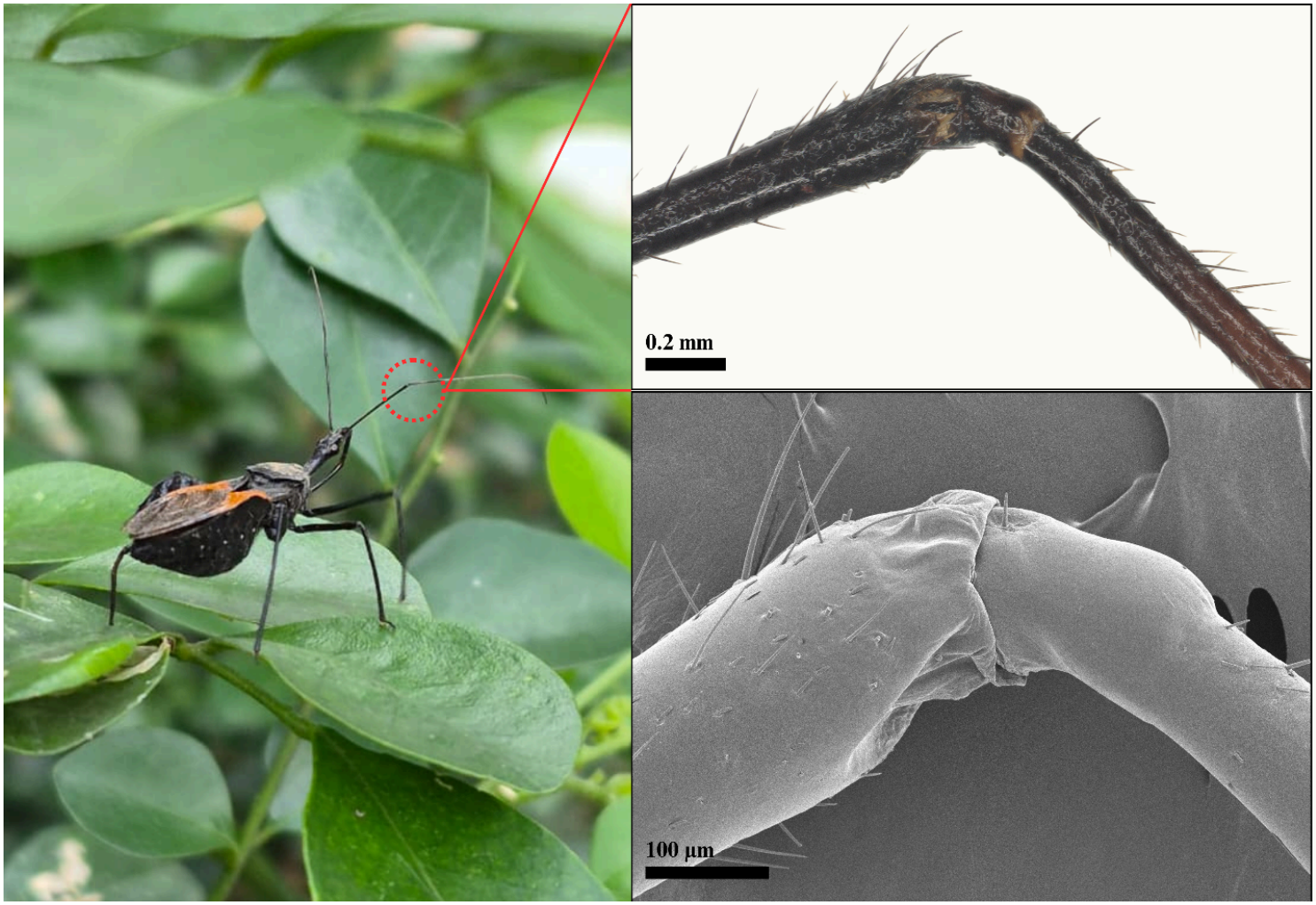

Figure 2

Morphological and microscopic observation of *Sycanus annulicornis*. Whole body habitus of the adult insect (left); stereomicroscopic and SEM observation of the geniculate antennae, showing detailed morphological features at scales of 0.2 mm and 100 µm.

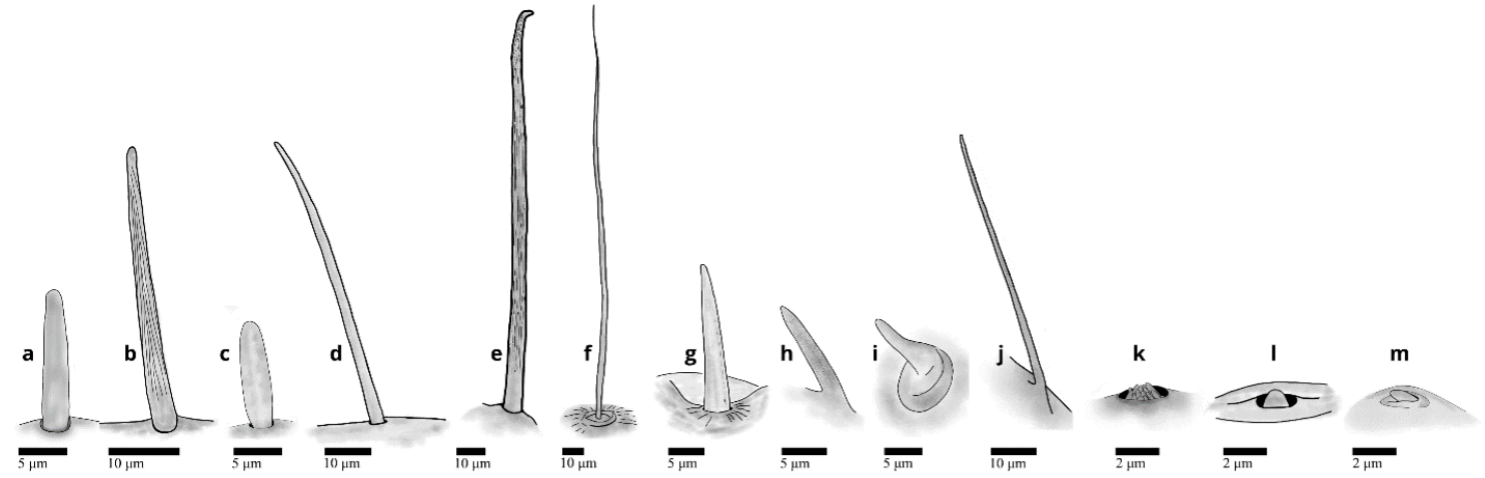

Figure 3

Illustration of all sensilla morphotypes. a-m: tI-tXIII.

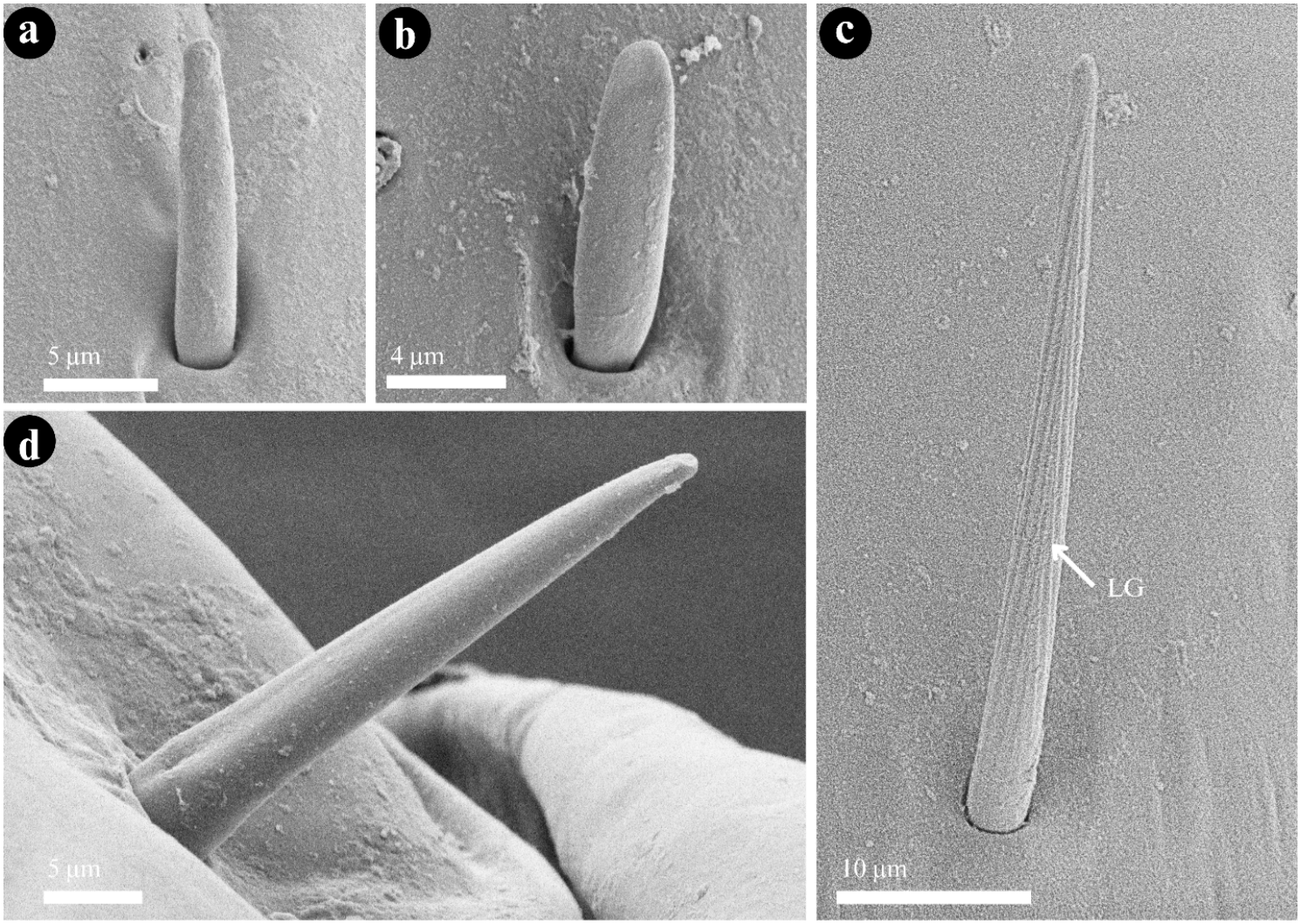

Figure 4

SEM observations of the antennae of *Sycanus annulicornis*. a: type I sensilla; b: type III sensilla; c: type II sensilla; d: type VII sensilla on the pedicle. LG: longitudinal grooves.

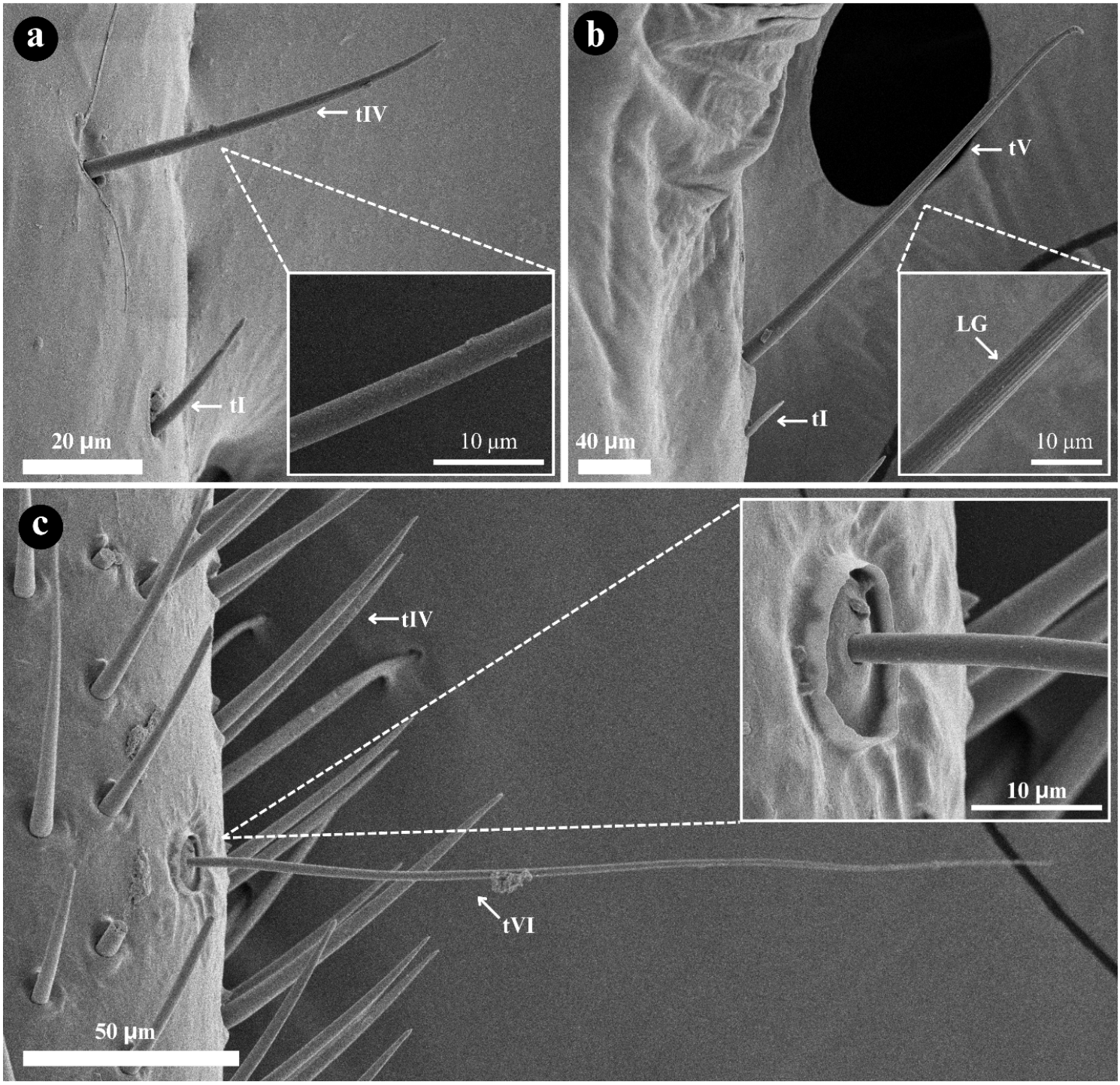

Figure 5

The types of sensilla observed on the antennae of studied species. a: Type I and Type IV sensilla, with a close-up view showing the surface of the Type IV sensilla; b: Type I and Type V sensilla, with a close-up view showing the surface of the Type V sensilla; c: Type VI sensilla, with a close-up view showing the base of the sensilla, which is shaped like a collar; LG: longitudinal grooves.

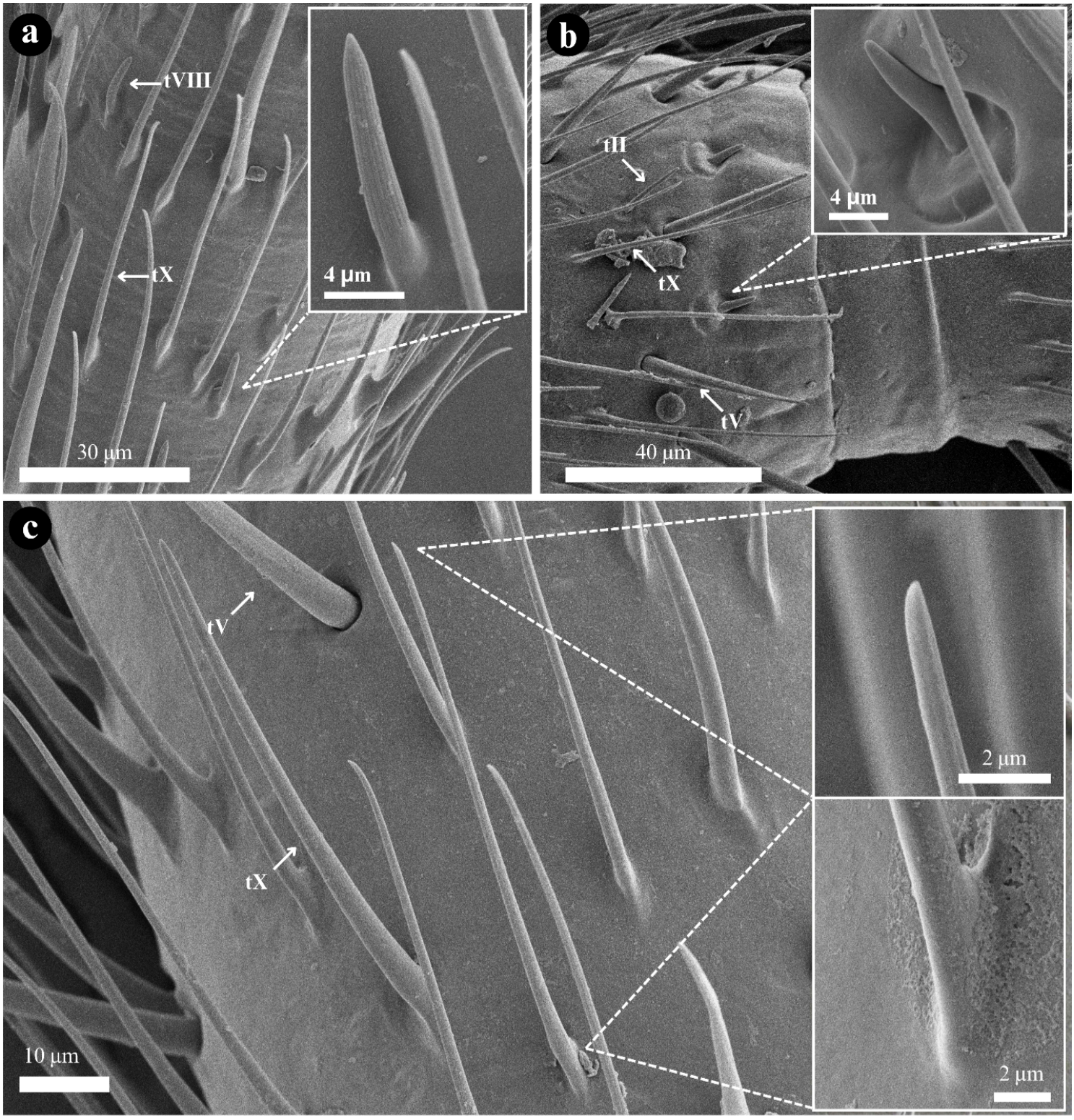

Figure 6

SEM observations of the antennae of *Sycanus annulicornis* show the distribution of sensilla and their morphological structure. a: type VIII sensilla, b: type IX sensilla, c: type X sensilla, LG: longitudinal grooves.

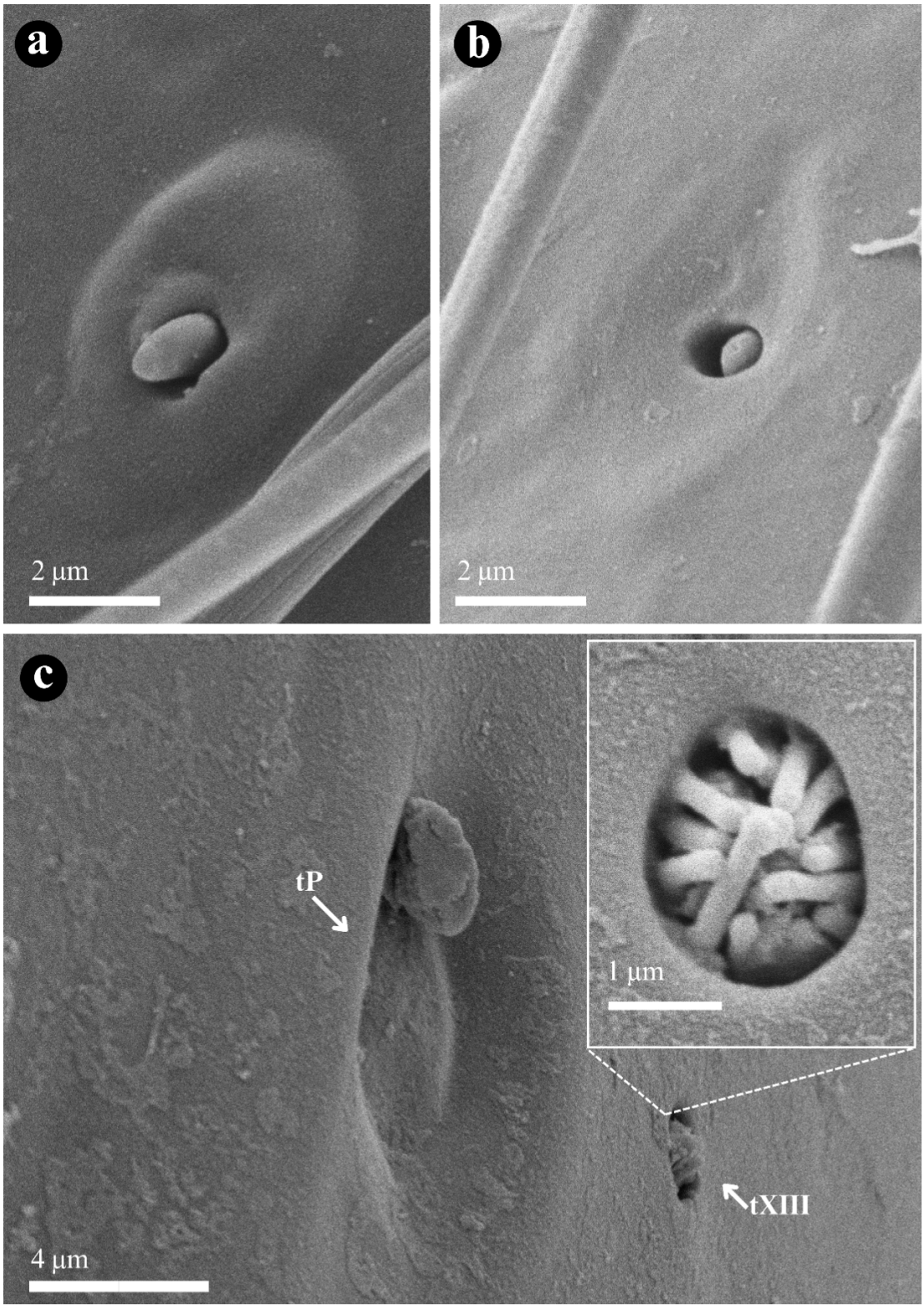

Figure 7

SEM observations of the antennae of *Sycanus annulicornis*. a: type XI sensilla, b: type XII sensilla, c: type XIII sensilla, tP: plate type.

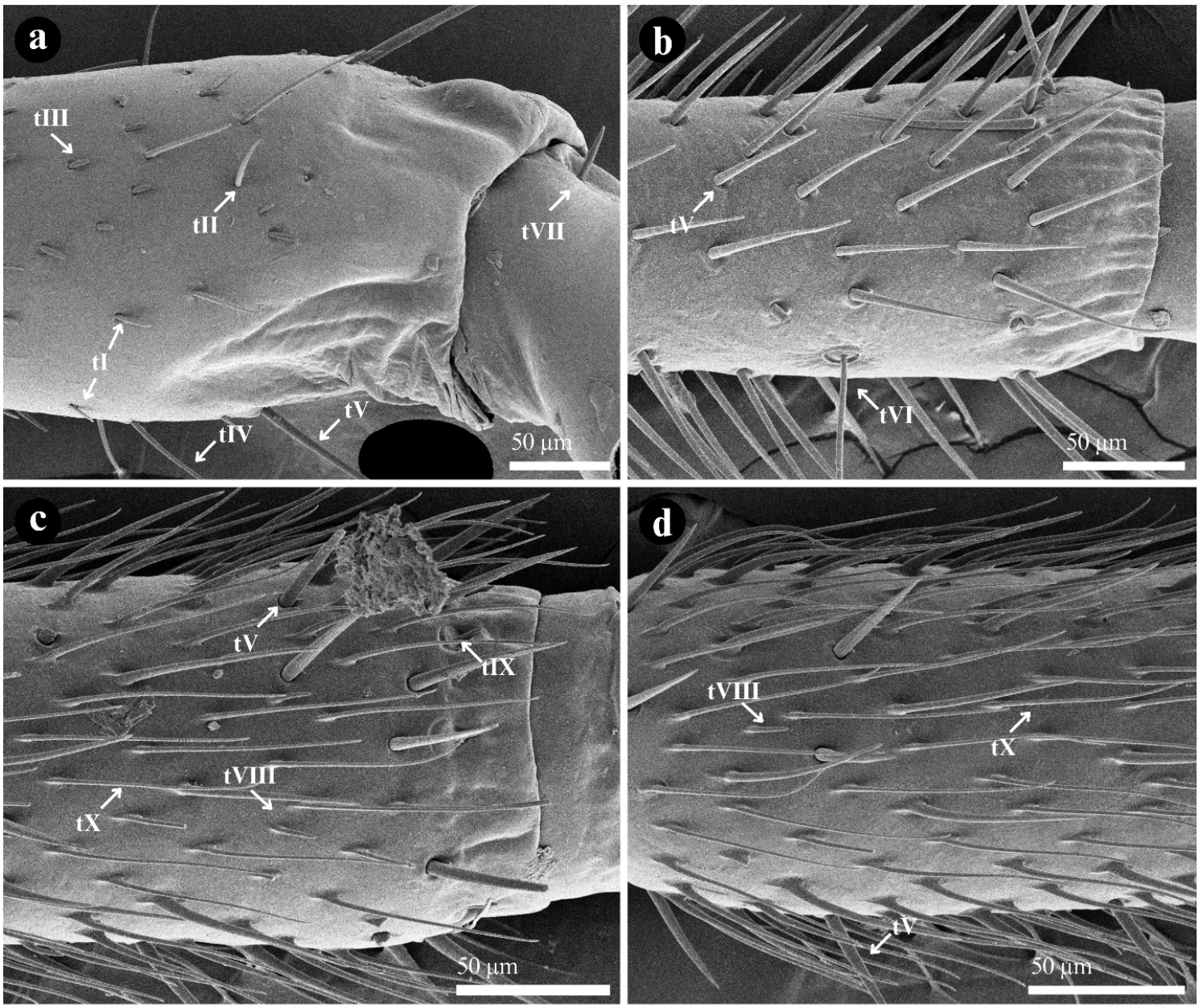

Figure 8

Distribution and density of sensilla on each antenna segment: a: scape; b: pedicel; c: post-pedicel; d: flagellum.

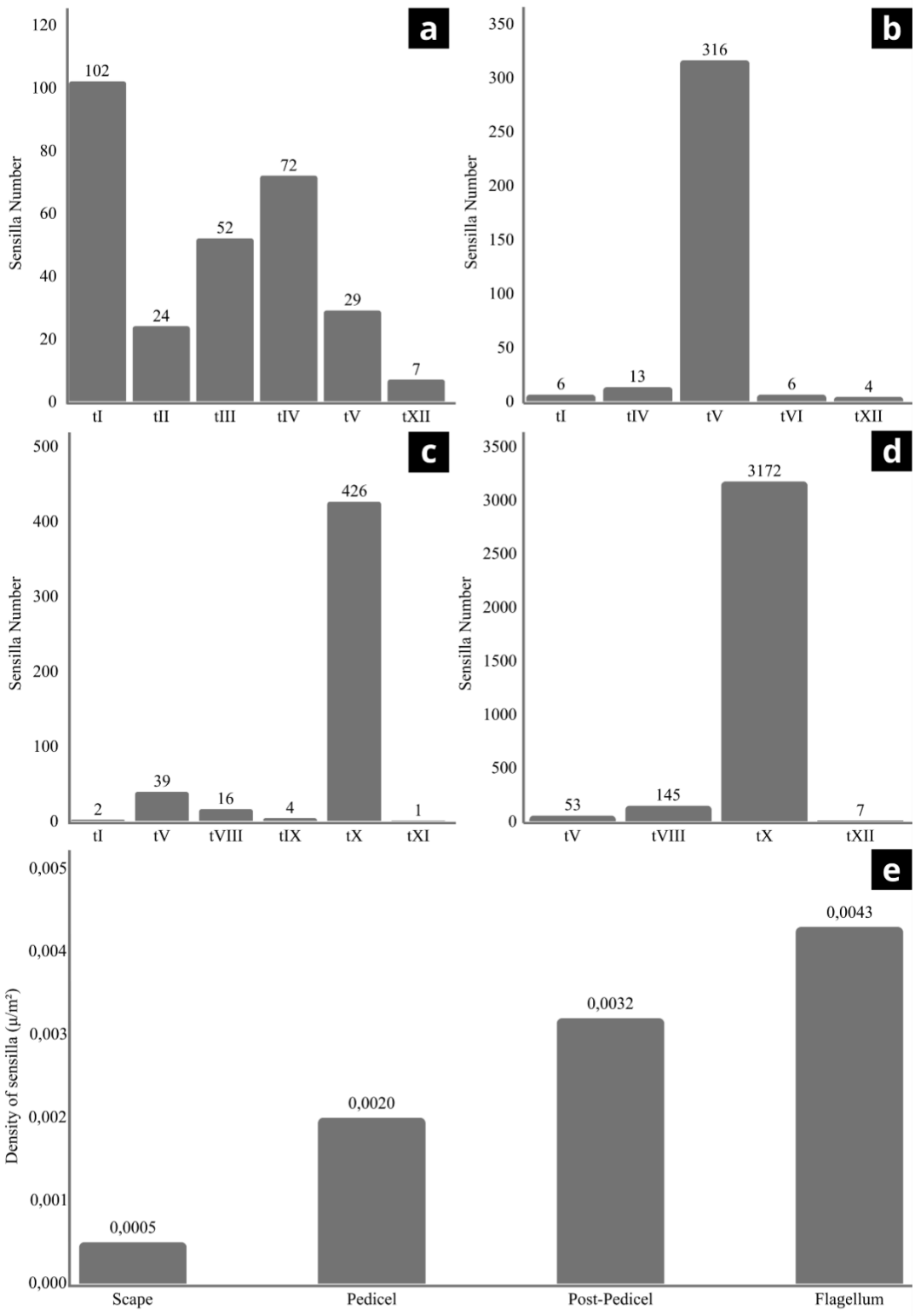

Figure 9

Distribution of the number and density of sensilla on each antenna segment: a: distribution of sensilla on the scape; b: distribution of sensilla on the pedicel; c: distribution of sensilla on the post-pedicel; d: distribution of sensilla on the flagellum; e: density of sensilla on each segment.