



## Fine structure of the mouthparts of *Diostrombus politus* and *Proutista moesta* (Hemiptera: Derbidae)<sup>☆</sup>

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### ARTICLE INFO

#### Keywords:

Fulgoroidea  
Phylogeny  
Ultrastructure

### ABSTRACT

Insect mouthparts are important sensory and feeding structures, morphological studies of this organ can provide additional data for phylogenetic studies. The planthopper superfamily Fulgoroidea is among the dominant groups of phytophagous insects, however, the mouthparts ultrastructure of this superfamily remains unsatisfactorily studied. This study investigates the ultrastructure of the mouthparts of two species in the family Derbidae (Hemiptera: Fulgoroidea), *Diostrombus politus* Uhler and *Proutista moesta* (Westwood), using a scanning electron microscope. The results show that these two derbids are of a typical piercing-sucking type found in Hemiptera. They consist of a cone-shaped labrum, a three-segmented labium and a stylet fascicle with two interlocked maxillary stylets incompletely wrapped by two mandibular stylets. The arrangement of the sensilla on the labial tip differ slightly between the two derbid species, and the subapical labial sensilla are likely different among genera in the family Derbidae.

### Introduction

Insect mouthparts are the cephalic parts and appendages that are involved in feeding and food ingestion (Zacharuk, 1985). The mouthparts of insects display a diversity of form and function. Thus, morphological studies can be used to reveal the feeding habits and feeding mechanisms of insects (Forbes, 1977; Cobben, 1978; Labandeira, 1997; Krenn, 2007; Chapman, 2013). In addition, mouthpart morphology provides excellent data for phylogenetic studies because the mouthparts throughout the orders of Insecta are composed of a set of homologous components which are ultimately derived from arthropod limbs (Krenn, 2007). Some recent studies have indicated that the structure of insects' mouthparts provide additional characters for taxonomy and phylogenetic analysis in insect orders (Scholtz, 1990; Sinclair, 1992; Ashe, 2000; Jameson et al., 2007; Weirauch, 2008; Beutel et al., 2009; Meier and Lim, 2009; Brožek and Bourgoïn, 2013b; Brožek, 2014). However, in such analyses it is necessary to examine the features of mouthparts from a number of representative taxa before the usefulness of mouthpart morphology in phylogenetic work can be evaluated.

The planthopper superfamily Fulgoroidea (Insecta: Hemiptera) is among the dominant groups of phytophagous insects, and includes about 13,000 species worldwide (O'Brien and Wilson, 1985; Bourgoïn et al., 2015). Members of this group have highly modified piercing-

sucking mouthparts and some of them are vectors for plant diseases, especially phytoplasmas which live in the phloem of plants and can be transmitted by planthoppers when feeding (Lee et al., 2000). Despite previous studies of mouthpart ultrastructure, the interlocking mechanisms of the maxillae and mandibles and the apical sensory tip of the labium of Fulgoroidea (Sōgawa, 1977, 1981; Foster et al., 1983a,b; Backus, 1985; Liang, 2001, 2005; Mora et al., 2001; Brožek et al., 2006; Zhang et al., 2011; Wang et al., 2012; Brožek and Bourgoïn, 2013a,b; Dai et al., 2014; Hao et al., 2016; Meng and Qin, 2017), the mouthparts ultrastructure of this superfamily remains unsatisfactorily studied.

The family Derbidae is the third largest family of Fulgoroidea (Yap and Bourgoïn, 2016). It includes approximately 1600 described species worldwide and most species are associated with monocots and particularly palms in the Arecaceae (Attié et al., 2008; Yap et al., 2015; Yap and Bourgoïn, 2016). To date, only the labial sensilla of *Proutista fritillaries* (Boheman) and the interlocking mechanism of the maxillae and mandibles of *Diostrombus gangunis* Van Stalle have been briefly described (Brožek et al., 2006; Brožek and Bourgoïn, 2013a,b). In the present work, the mouthpart morphology of *Diostrombus politus* and *Proutista moesta* are studied. The aim of this study is to find more morphological evidence that may be useful for future studies in taxonomy and phylogeny of the superfamily Fulgoroidea, especially within Derbidae.

<sup>☆</sup> All authors have read and approved to submit the manuscript "Fine structure of the mouthparts of *Diostrombus politus* and *Proutista moesta* (Hemiptera: Derbidae)" to your journal Journal of Asia-Pacific Entomology. There is no conflict of interest of any authors in relation to the submission. This paper has not been submitted elsewhere for consideration of publication.

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**Fig. 1.** Scanning electron micrographs (SEMs) of the mouthparts of adult *Diostrombus politus*. (A) Anterior view. (B) Lateral view. (C) Posterior view showing the three labial segments. Cl, clypeus; I–III, three segments of labium; Lb, labium; Lg, labial groove; Lm, labrum; MJ, membranous joint between the first and second segments; Sf, stylet fascicle. Scale bars: (A) = 200 μm; (B) and (C) = 250 μm.

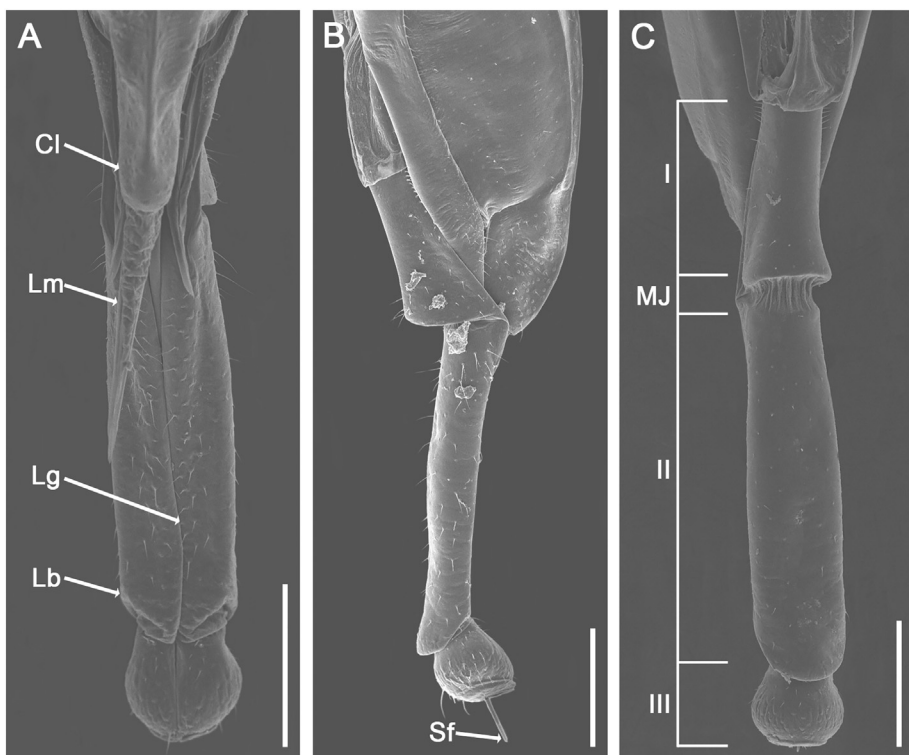
**Materials and methods**

*Sample preparation for scanning electron microscopy*

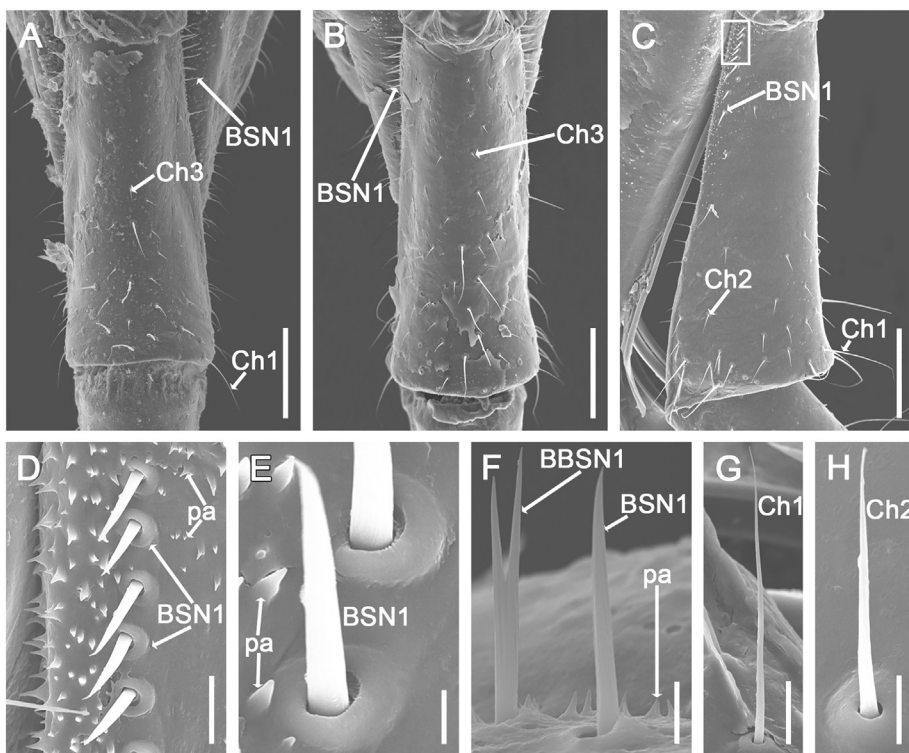
Adults of *P. moesta* were collected at Huaping in Guilin, Guangxi Province, China in July 2014 (N 25°37'57.88" and E 109°54'32.39") and *D. politus* were collected from Hongya in Emei, Sichuan Province,

China in July 2015 (N 29°34'31.95" and E 103°14'56.25"). All the specimens were preserved in 70% ethanol. Voucher specimens were deposited in the Entomological Museum of Northwest A&F University.

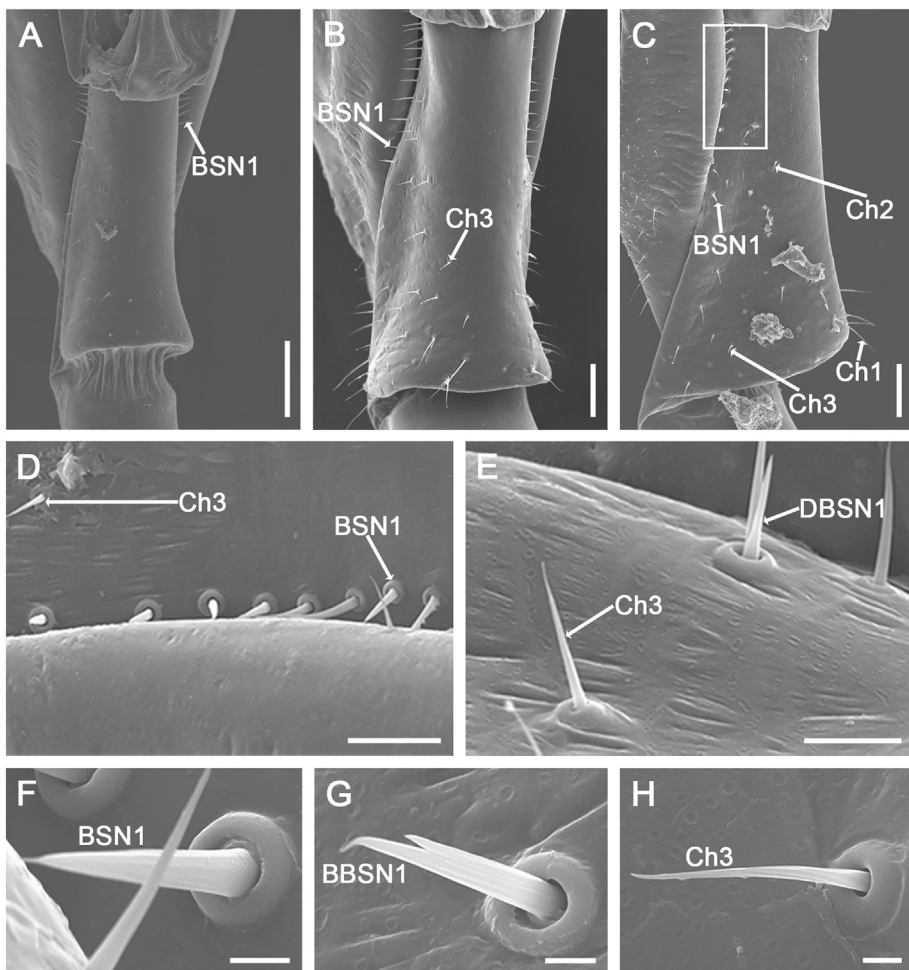
The specimens used in this study were randomly-selected, with seven specimens of each species. The fixed specimens were dehydrated in a graded series of 75%, 80%, 85%, 90%, and 95% ethanol for 20 min each and in 100% ethanol twice for 30 min. After air-drying for 24 h,



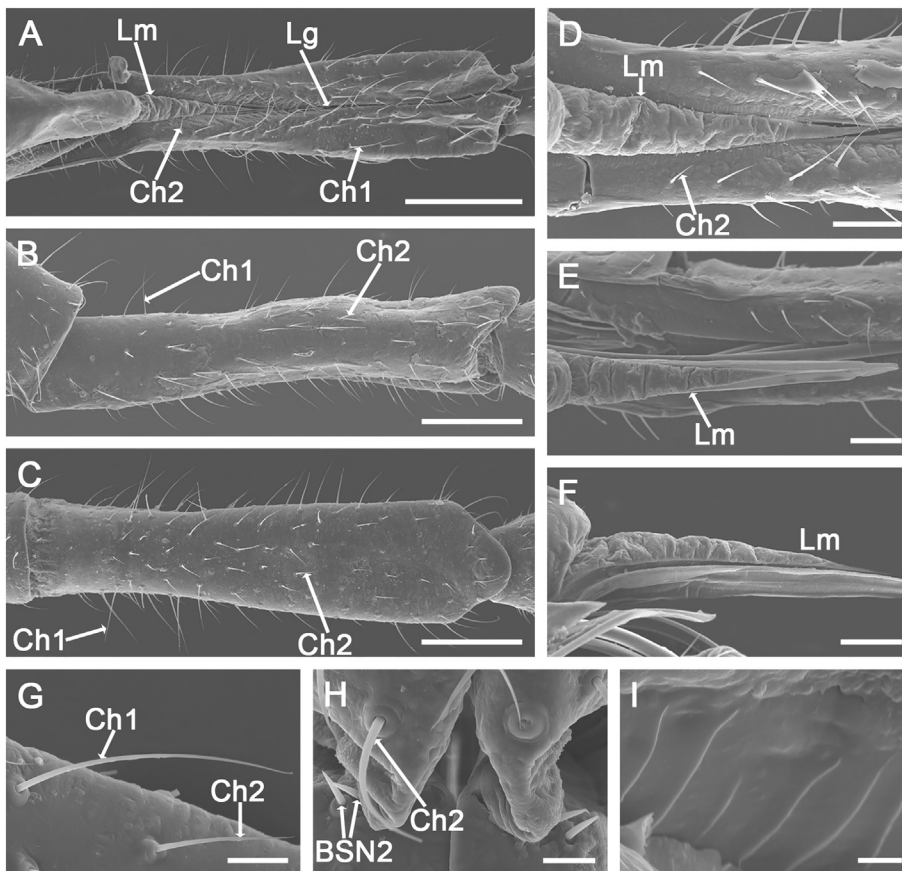
**Fig. 2.** Scanning electron micrographs (SEMs) of the mouthparts of adult *Proutista moesta*. (A) Anterior view. (B) Lateral view. (C) Posterior view showing the three labial segments. Cl, clypeus; I–III, three segments of labium; Lb, labium; Lg, labial groove; Lm, labrum; MJ, membranous joint between the first and second segments; Sf, stylet fascicle. Scale bars: (A), (B) and (C) = 250 μm.



**Fig. 3.** SEM of the first segment of labium of *D. politus*. (A) Ventral view of the first labial segment and the membranous joint. (B) Ventral view of the first labial segment. (C) Lateral view of the first labial segment. (D) Enlarged view of outlined box of (C), showing the sensilla basiconica subtype I and the papillae. (E) Sensilla basiconica subtype I. (F) Bifurcated sensillum basiconica subtype I. (G) Sensillum chaetica subtype I. (H) Sensillum chaetica subtype II. Ch1–3, sensilla chaetica subtypes I–III; BSN1, sensilla basiconica subtype I; BBSN1, bifurcated sensillum basiconica subtype I; pa, papillae. Scale bars: (A), (B) and (C) = 100  $\mu$ m; (D) = 10  $\mu$ m; (E) and (I) = 2.5  $\mu$ m; (F) and (H) = 5  $\mu$ m; (G) = 15  $\mu$ m.



**Fig. 4.** SEM of the first segment of labium of *P. moesta*. (A) Ventral view of the first labial segment and the membranous joint. (B) Ventral view of the first labial segment. (C) Lateral view of the first labial segment. (D) Enlarged view of outlined box of (C), showing the sensilla basiconica subtype I. (E) Sensilla chaetica subtype III and deformed sensillum basiconica subtype I with linear and rounded nicks. (F) Sensillum basiconica subtype I. (G) Bifurcated sensillum basiconica subtype I. (H) Sensillum chaetica subtype III. Ch1–3, sensilla chaetica subtypes I–III; BSN1, sensilla basiconica subtype I; BBSN1, bifurcated sensillum basiconica subtype I. Scale bars: (A) = 100  $\mu$ m; (B) and (C) = 50  $\mu$ m; (D) = 20  $\mu$ m; (E) = 10  $\mu$ m; (F), (G) and (H) = 2.5  $\mu$ m.



**Fig. 5.** SEM of the labrum and the second segment of labium of *D. politus*. (A) Anterior view of the second segment. (B) Lateral view of the second segment. (C) Ventral view of the second segment. (D) Anterior view of labrum which is concealed by the labial groove. (E) Anterior view of labrum. (F) Lateral view of labrum. (G) Sensillum chaetica subtype I and sensillum chaetica subtype II. (H) Enlarged view of junction of the second and the third segment. (I) Enlarged view of the transverse ridge on both sides of labium groove. Ch1–2, sensilla chaetica subtypes I–II; BSN2, sensilla basiconica subtype II; Lg, labial groove; Lm, labrum. Scale bars: (A) = 200  $\mu\text{m}$ ; (B) and (C) = 150  $\mu\text{m}$ ; (D) and (E) = 50  $\mu\text{m}$ ; (F) and (G) = 20  $\mu\text{m}$ ; (H) = 15  $\mu\text{m}$ ; (I) = 2.5  $\mu\text{m}$ .

the specimens were sputter-coated with gold in a MSP-1S high resolution sputter coater (Hitachi, Japan). Thereinto, the structure of mouthparts was analysed in cross-section through the subapical rostral segment of specimens (Brožek et al., 2006). Observations and micrographs were carried out under an S-3400N scanning electron microscope (Hitachi, Japan) at 15 kV.

#### Terminology

The terminology of the connecting systems between maxillae and mandibles and the sensilla on the labial tip follows Brožek et al. (2006) and Brožek and Bourgoin (2013a). For classification of sensilla, we follow Schneider (1964) and Zacharuk (1985).

#### Results

##### Gross morphology of the mouthparts

This study show that the mouthpart morphology of these two derbid species are generally similar to that of other planthoppers and display a number of traits derived within the Fulgoromorpha. Both have the typical piercing-sucking type, arising from the posterior part of the head capsule (Figs. 1B, 2B) and consist of a cone-shaped labrum (Figs. 1A, 2A), a tubular labium subdivided into three different length segments (Figs. 1C, 2C) and a stylet fascicle (Figs. 1B, 2B). The anterior surface of

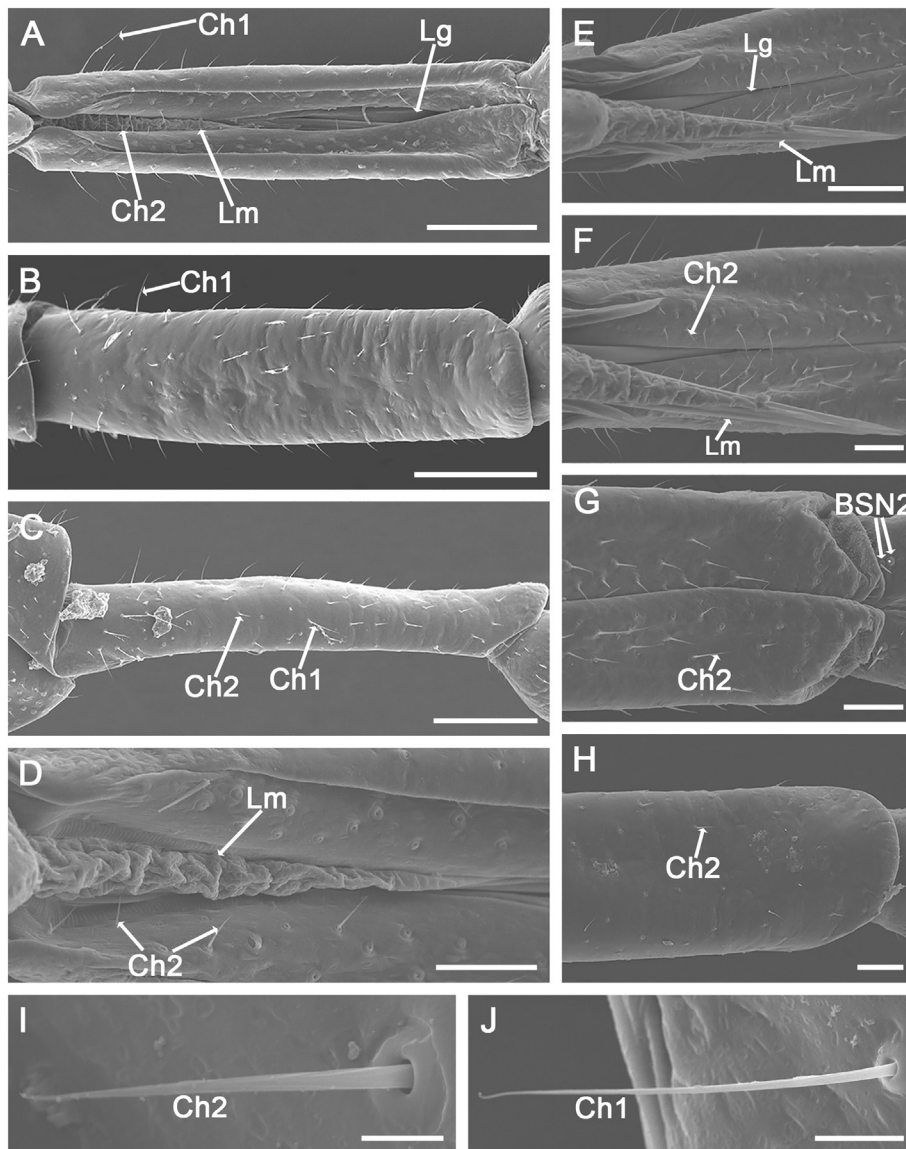
the labium was bisected by a longitudinal labial groove (Figs. 1A, 2A) which encircles the stylet fascicle which consists of two inner maxillary stylets incompletely surrounded by two relatively shorter mandibular stylets. Various types of sensilla are distributed on the mouthparts (Figs. 3–9) (Table 2). The primary mouthpart structures of *D. politus* and *P. moesta* are similar, and some specific structural details are different (Table 1).

##### Labrum

The conical labrum is attached along the posterior margin to the anteclypeus. The labrum overlaps part of the labial groove of the second labial segment, around one third of the labial groove in *D. politus* (Fig. 5A), but approximately half in *P. moesta* (Fig. 6A). The most anterior surface of the labrum is plicate but the distal section is smooth (Figs. 5E, F, 6E, F). Two flat lateral portions are smooth and normally lay concealed inside the labial groove (Figs. 5D, 6D). The labrum is relatively straight and gradually tapers to the tip (Figs. 5E, 6E).

##### Labium

The labium is modified as a rostrum and contains three segments (Figs. 1C, 2C). The anterior surface of the labium is bisected by a labial groove which extends the entire length (Figs. 1A, 2A). Sensilla are



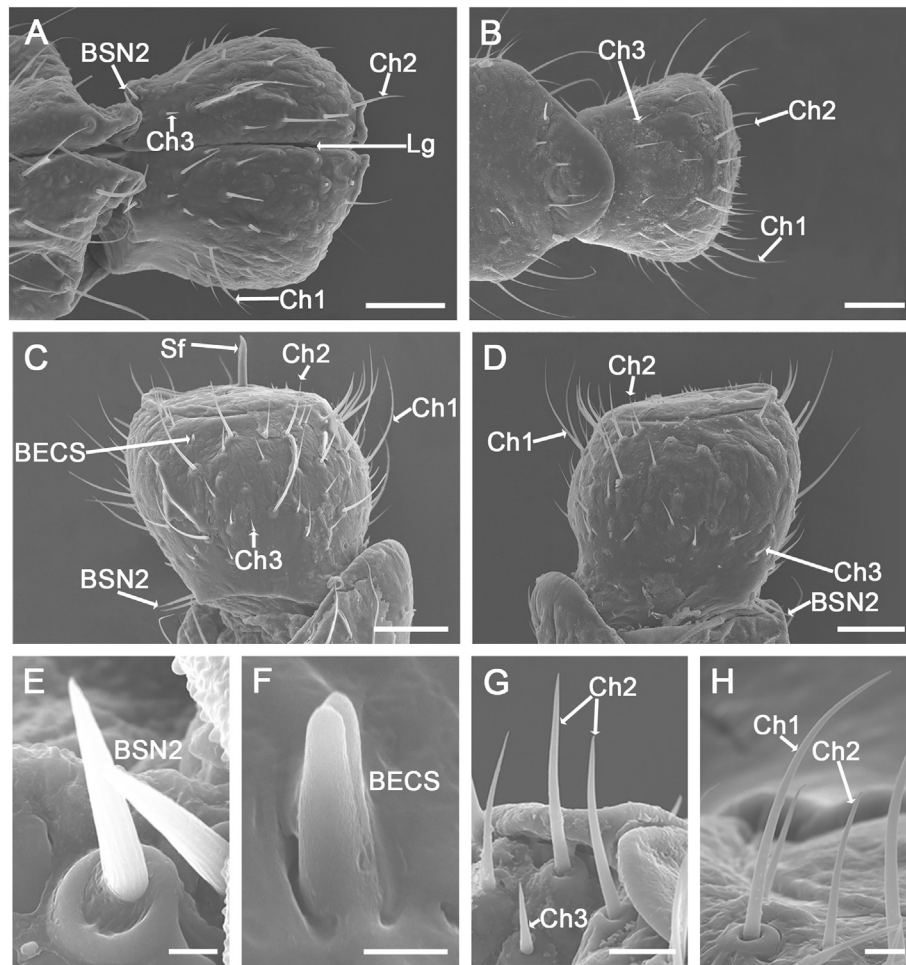
**Fig. 6.** SEM of the labrum and the second segment of labium of *P. moesta*. (A) Anterior view of the second segment. (B) Ventral view of the second segment. (C) Lateral view of the second segment. (D) Anterior view of the labrum which conceals by the labial groove. (E) Anterior view of labrum. (F) Anterior view of basal portion of the second segment and the distal portion of the labrum. (G) Anterior view of the basal portion of the second segment. (H) Ventral view of distal portion of the second segment. (I) Sensillum chaetica subtype II on both sides of labium groove. (J) Sensillum chaetica subtype I. Ch1–2, sensilla chaetica subtypes I–II; BSN2, sensilla basiconica subtype II; Lg, labial groove; Lm, labrum. Scale bars: (A), (B) and (C) = 150  $\mu$ m; (D), (F), (G) and (H) = 50  $\mu$ m; (E) and (J) = 100  $\mu$ m; (I) = 5  $\mu$ m.

widely distributed on each side of the labial groove and on the dorsal surfaces; relatively fewer are present on the lateral surfaces (Figs. 3–8). The tip of the third labial segment is flattened with an opening from which the apices of the stylets protrude (Figs. 7C, 8B, C).

The first labial segment is concealed by the overlapping anteclypeus (Figs. 1B, 2B). The lateral and posterior surfaces are smooth, ten sensilla basiconica subtype I (BSN1) and some papillae are present on the basal one-third of the lateral margins in *D. politus* (Fig. 3A–D). The lateral surface has numerous nicks and ten BSN1 are present on the lateral margins in *P. moesta* (Fig. 4A–E). The BSN1 are short, straight, with blunt tips and longitudinal grooves, projecting out from an obviously convex round base, and are almost perpendicular to the surface (Figs. 3E, F, 4F, G). Three subtypes of sensilla chaetica (Ch1, Ch2 and Ch3) are present on the lateral and posterior surface; relatively more are present on the distal section of the first labial segment (Figs. 3A–C, 4A–C). Sensilla chaetica subtype I (Ch1) are slender, frequently curved

with pointed tips, and insert into flexible sockets; their surface has longitudinal grooves (Figs. 3G, 6J). Sensilla chaetica subtype II (Ch2) and sensilla chaetica subtype III (Ch3) resemble Ch1 in their morphology but they are relatively shorter and straighter. Ch3 are the shortest ones (Figs. 3H, 4H, 5G, 6I). The membranous joint between the first and second labial segments is excessively constricted and possesses longitudinal wrinkles (Figs. 3A, 4A).

The second labial segment is the longest of the three segments (Figs. 1C, 2C). The distal margin of posterior surface is elongate and obviously covers the basal part of the third segment (Figs. 1C, 2C). The distal margin of the anterior surface on the each side of the labial groove is folded and extends to form a triangle, with one thick Ch2 (~47  $\mu$ m) in *D. politus* (Fig. 5A, H). This triangle is not apparent in *P. moesta* (Fig. 6G). On the anterior surface of this segment, a line of transverse ridges approaches the two sides of the labial groove present on the basal half part of this segment in *D.*



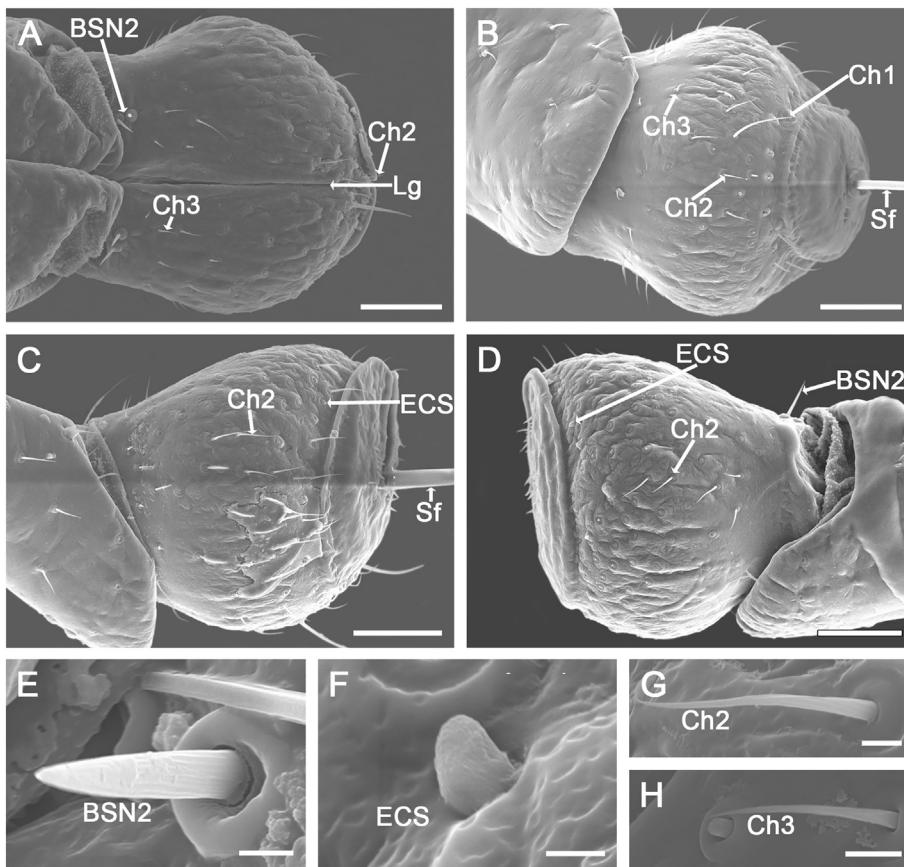
**Fig. 7.** SEM of the third segment of labium of *D. politus*. (A) Anterior view. (B) Ventral view. (C) Right lateral view. (D) Left lateral view. (E) Sensilla basiconica subtype II at base of the third segment. (F) Bifurcate elevated cone-like sensillum. (G) Enlarged view of sensilla chaetica subtype II and sensillum chaetica subtype III. (H) Enlarged view of sensilla chaetica subtype I and sensilla chaetica subtype II. Ch1–3, sensilla chaetica subtypes I–III; BSN2, sensilla basiconica subtype II; BECS, bifurcate elevated cone-like sensillum; Lg, labial groove; Sf, stylet fascicle. Scale bars: (A), (B), (C) and (D) = 50  $\mu$ m; (E) and (F) = 2.5  $\mu$ m; (G) = 10  $\mu$ m; (H) = 5  $\mu$ m.

*politus* (Fig. 5A, D, E); but this line of ridges is approximately one fourth of the labial groove in *P. moesta* (Fig. 6D–F). A large number of Ch1 and Ch2 are symmetrically located on each side of the labial groove (Figs. 5A, D, 6A, F, G). A small number of Ch1 and Ch2 are present in the area of the lateral and posterior surfaces of the segment (Figs. 5B, C, G, 6B, C, H).

The third labial segment is shortest (Figs. 1C, 2C). The distribution of sensilla on the third segment resembles the second segment; a small number of Ch3 are sporadically located on this segment (Figs. 7A–D, 8A–D, 8H). Ch1 are mainly present on the anterior and lateral surfaces (Figs. 7H, 8G). Ch2 are largely distributed on the distal margin of this segment (Figs. 7B–D, G, H, 8B, C, G). At the junction with the second segment, there are two pairs of sensilla basiconica subtype II (BSN2) located on both sides of the labial groove (Figs. 5A, C, D, 6A, D). The BSN2 resemble but are thicker than BSN1 (Figs. 5E, 6E). On each lateral surface of the third segment, close to the labial tip, an elevated cone-like sensillum (ECS) is found in *P. moesta* (Fig. 8F), but the one in *D. politus* is

bifurcate (BECS) (Fig. 7F). The ECS is cone-shaped with a rounded tip; the cuticle wall is uneven. The BECS is more slender than the ECS, bifurcate and possesses two pores at its base, has a rough cuticular wall and is covered with tiny pores.

The labial tip possesses two dorsal sensory fields symmetrically situated on each side of the stylet groove; ventral sensory fields are located behind the stylet groove (Fig. 9A, B). The sensillar types of the labial tip are similar between the two species, but the sensillar distributions are slightly different (Fig. 10A, B). Each dorsal sensory field is subdivided into two flat sensory fields (field A and field B); four sensilla basiconica subtype III (BSN3, Nos. 1–4, 5.1–7.8  $\mu$ m) are on fields A (Fig. 9F–H), field B contains one multiporous dome-shaped sensillum (DSSM, No. 5) with five uniporous clavate-like sensilla (CLSU, Nos. 6–10) with the No. 9 sensillum being the biggest (Fig. 9C, D, I). The sensilla (Nos. 6–10) are grouped together and the No. 5 sensillum is far from these groups in *P. moesta* (Figs. 9B, 10B), but the No. 5 sensillum is in the centre of these groups in *D. politus* (Figs. 9A, 10A). Two short BSN3 (Nos. 11–12,



**Fig. 8.** SEM of the third segment of labium of *P. moesta*. (A) Anterior view. (B) Ventral view. (C) Right lateral view. (D) Left lateral view. (E) Sensillum basiconica subtype II at base of the third segment. (F) Elevated cone-like sensillum. (G) Sensillum chaetica subtype II. (H) Sensillum chaetica subtype III. Ch1–3, sensilla chaetica subtypes I–III; BSN2, sensilla basiconica subtype II; ECS, elevated cone-like sensillum; Lg, labial groove; Sf, stylet fascicle. Scale bars: (A), (B), (C) and (D) = 50  $\mu$ m; (E) = 2.5  $\mu$ m; (F) = 2.5  $\mu$ m; (G) = 5  $\mu$ m.

3.0–4.7  $\mu$ m) are found in each ventral sensory field; the two sensilla are distant from the opening in *D. politus* (Figs. 9A, 10A). Two BSN3 are in close contact with the opening of the stylets from which they protrude from the labium, and the location of the No. 11 and 12 sensilla are horizontal in *P. moesta* (Figs. 9B, 10B). The multiporous dome-shaped sensillum (DSSM) sinks into an inflexible socket (Fig. 9I). Uniporous clavate-like sensilla (CLSU) are slender and their length varies considerably (5–9  $\mu$ m); they are slightly curved with blunt top (Fig. 9C, D).

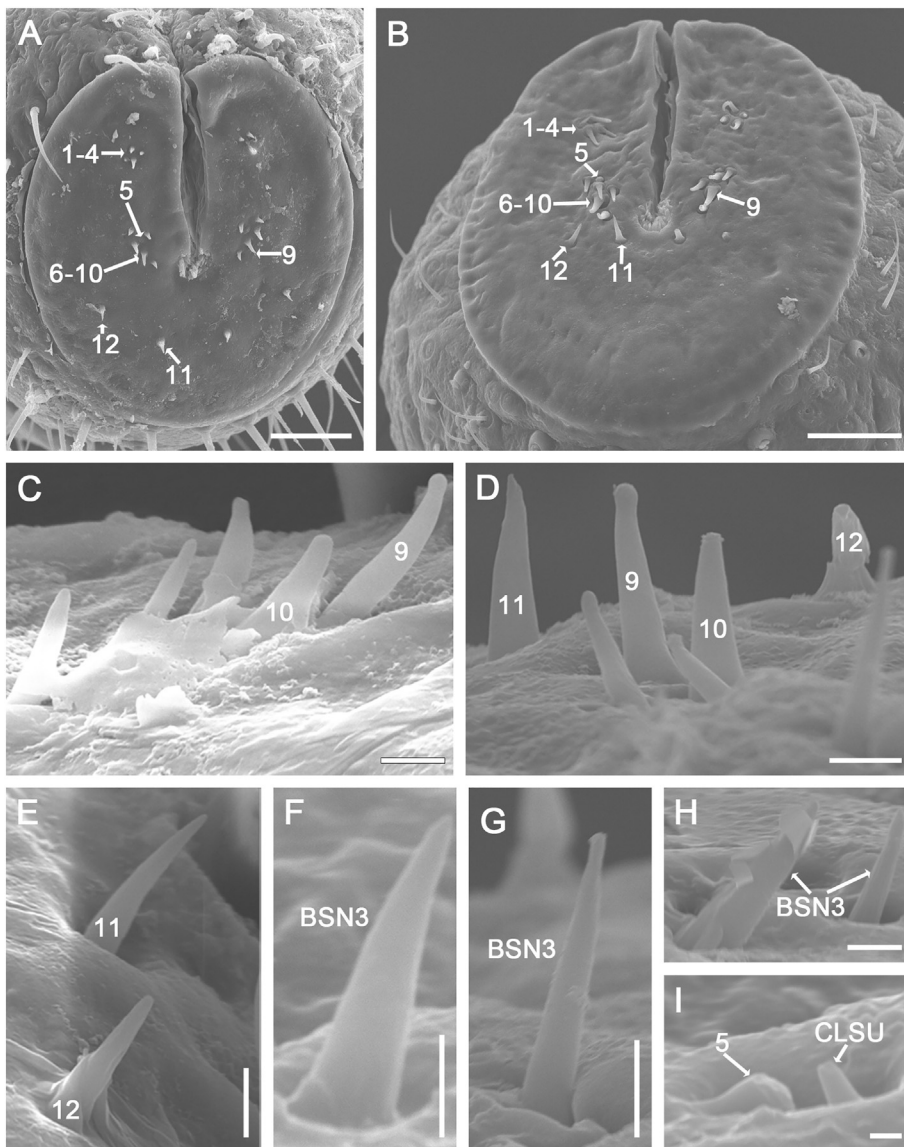
#### Stylet fascicle

The needle-like stylet fascicle (Fig. 11D) contains two mandibular and two maxillary stylets wrapped in the labium and protruding from the labial tip (Figs. 11C, 12A, F). The diameter of the stylet fascicle is approximately 16.3  $\mu$ m in *D. politus* (~16.0  $\mu$ m in *P. moesta*) (Figs. 11A, B, 12E), and the average length of the mandibular and maxillary stylets is about 781 and 793  $\mu$ m respectively in *D. politus* (about 832 and 888  $\mu$ m in *P. moesta*).

The mandibular stylets are approximately semicircular in cross-section respectively in *P. moesta* and *D. politus* (Figs. 11A, B, 12E), located on each outer side of the maxillary stylets. The mandibular stylets envelop two curved maxillary stylets which are held together tightly. The inner surfaces of the mandibular stylets are smooth (Figs. 11I, 12G, D), making it convenient for free movement of these maxillary stylets to probe plant tissues. The convex ventral surface of the mandibular

stylets contains some unapparent protuberances which are located at the extreme tip of the stylet (Figs. 11H, 12G, H). The cross-section of this stylet fascicle shows that each mandibular stylet has a dendritic canal (Figs. 11B, 12E) which runs throughout the stylet centrally in each stylet.

In contrast to the mandibles, the maxillary stylets are asymmetrical and complex (Figs. 11A, B, 12E). The external surface of the maxillary stylets is smooth (Figs. 11E, F, 12C). The two maxillary stylets are held together by internal longitudinal grooves and their interlocking mechanism along their length; this is approximately oblong-shaped in cross-section in *D. politus* and *P. moesta* (Figs. 11A, B, 12B, D, E). The apical parts of the maxillary stylets are blunt and incurved, having more incision in *P. moesta* (the tips of the maxillary stylets are more pointed in *D. politus*) (Figs. 11E–F, 12B–D). The two internal longitudinal grooves interlock with each other forming a food canal used to suck plant juice, and a salivary canal that directs saliva to the plant. The hollow food canal is approximately oval in cross-section and located in the center due to the symmetrically concave inner walls of the two stylets. The salivary canal is located laterally on the inner side as the stylets interlock and is approximately circular (Figs. 11A, B, F, 12E, D). The diameter of the food canal and salivary canal is about  $2.87 \times 2.17 \mu$ m and  $1.48 \times 1.72 \mu$ m in *P. moesta* these numerical values for *D. politus* are  $2.50 \times 2.11 \mu$ m and  $1.15 \times 1.22 \mu$ m respectively. The food and salivary canals extend proximal to the stylet tip. Within each maxillary stylet there are two circular dendritic canals, one is



**Fig. 9.** Distribution of various sensilla on labial tip of derbids. (A) SEM views of labial tip of *D. politus*. (B) SEM views of labial tip of *P. moesta*. (C) View of five uniporous clavate sensilla on the field B of the dorsal sensory field. (D) Uniporous clavate sensilla on the field B of the dorsal sensory field and two sensilla basiconica subtypes III on the ventral sensory field. (E) Two sensilla basiconica subtypes III on the ventral sensory field. (F), (G) and (H) View of sensilla basiconica subtypes III on the field A of the dorsal sensory field. (I) View of the multiporous dome-shaped sensillum and one broken uniporous clavate sensillum on the field B of the dorsal sensory field. Nos. 1–4, sensilla basiconica subtype III on the field A of the dorsal sensory field; No. 5, multiporous dome-shaped sensillum on the field B of the dorsal sensory field; Nos. 6–10, uniporous clavate-like sensilla on the field B of the dorsal sensory field; Nos. 11–12, sensilla basiconica subtype III on the ventral sensory field; BSN3, sensilla basiconica subtype III; CLSU, uniporous clavate-like sensillum. Scale bars: (A) and (B) = 25 μm; (C), (D), (E) and (G) = 2.5 μm; (F) = 1 μm; (H) = 1.5 μm; (I) = 0.5 μm.

**Table 1**  
The morphometric data of mouthparts of *Diostrombus politus* and *Proutista moesta*.

	<i>Diostrombus politus</i>			<i>Proutista moesta</i>		
	Length (μm)	Width (μm)	N	Length (μm)	Width (μm)	N
Labrum	234.4 ± 17.29	49.42 ± 2.42	4	369.96 ± 19.56	54.36 ± 3.79	4
Labium	1155.82 ± 73.15	175.61 ± 3.39	4	1201.37 ± 76.83	176.67 ± 3.97	4
Lb-1	387.20 ± 14.54	165.77 ± 2.33	4	364.11 ± 27.33	160.14 ± 21.93	4
Lb-2	698.21 ± 49.62	171.41 ± 17.07	6	686.05 ± 41.30	157.75 ± 7.47	5
Lb-3	149.91 ± 24.40	160.78 ± 11.37	6	151.21 ± 8.19	178.34 ± 9.77	6

Data are means ± SE values acquired from scanning electron microscopy. N = sample number; Lb1–3, three segments of labium.



**Table 2**  
Distribution and morphometric data of various sensilla in mouthparts of *Diostrombus politus* and *Proutista moesta*.

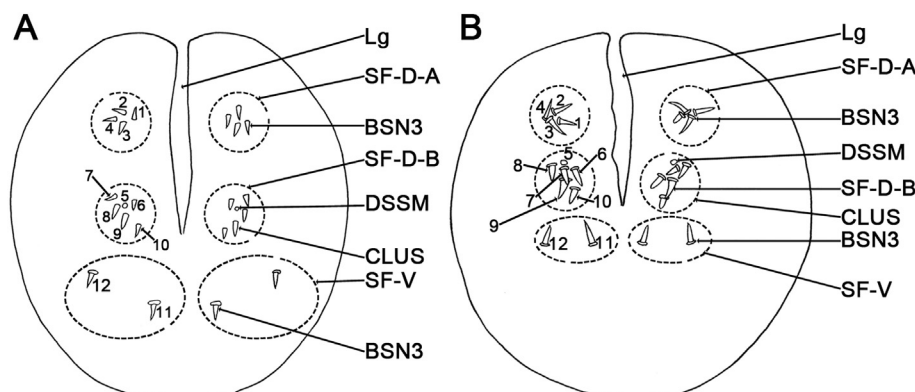
Sensilla type	<i>Diostrombus politus</i>				<i>Proutista moesta</i>			
	Distribution	Length (µm)	Basal diameter (µm)	N	Distribution	Length (µm)	Basal diameter (µm)	N
BSN1	Lb-1	17.61 ± 3.33	1.65 ± 0.45	10	Lb-1	18.11 ± 0.81	1.91 ± 0.19	10
BSN2	Lb-3	19.69 ± 7.62	2.56 ± 0.22	6	Lb-3	17.17 ± 4.40	2.37 ± 0.10	6
BSN3	SF-D-A, SF-V	4.33 ± 1.17	1.25 ± 0.32	5	SF-D-A, SF-V	5.60 ± 1.21	1.56 ± 0.20	16
Ch1	Lb	78.69 ± 11.02	2.49 ± 0.55	10	Lb	63.10 ± 11.71	1.93 ± 0.17	11
Ch2	Lb	30.83 ± 7.87	2.25 ± 0.23	18	Lb	33.51 ± 5.74	1.73 ± 0.25	11
Ch3	Lb-1, Lb-3	10.29 ± 2.17	1.83 ± 0.46	10	Lb-1, Lb-3	16.22 ± 3.33	1.30 ± 0.21	14
SALS	Lb-3 (BECS)	6.64	2.50	2	Lb-3 (ECS)	4.50 ± 0.43	3.02 ± 0.53	3
CLSU	SF-D-B	6.67	1.12	2	SF-D-B	6.18 ± 1.76	1.27 ± 0.62	15
DSSM	SF-D-B		0.97	2	SF-D-B		1.88	2

Data are means ± SE values obtained from scanning electron microscopy. N = sample number; BSN1–3, sensilla basiconica subtypes I–III; Ch1–3, sensilla chaetica subtypes I–III; SALS, subapical labial sensillum; BECS, bifurcate elevated cone-like sensillum; ECS, elevated cone-like sensillum; CLSU, uniporous clavate-like sensillum; DSSM, multiporous dome-shaped sensillum; Lb1–3, three segments of labium; SF-D-A, flat field A of dorsal sensory field on the labial tip; SF-D-B, flat field B of dorsal sensory field on the labial tip; SF-V, ventral sensory field on the labial tip.

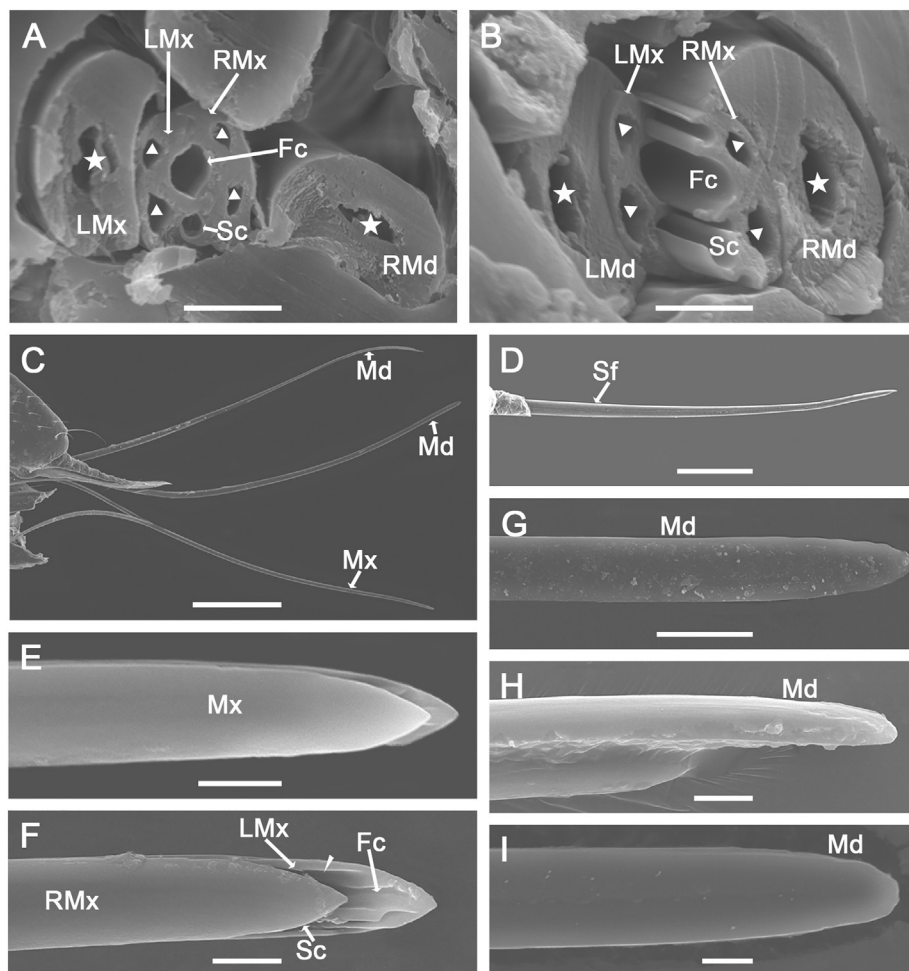
**Table 3**  
Main features of mouthparts of derbids (Derbidae).

Species name	Subapical labial sensillum	Stylet fascicle		Apical labial sensilla						References
		Shape of the mandibular stylet in cross-section	Shape of the interlocking maxillary stylets in cross-section	SF-D-A (one side)		SF-D-B (one side)		SF-V (one side)		
				Sensilla type	The number of sensilla	Sensilla type	The number of sensilla	Sensilla type	The number of sensilla	
<i>Diostrombus politus</i>	Cone-like	Semicircular	Oblong-shaped	BSN	4	CLSU	5	BSN	2	This study
<i>Diostrombus gangumis</i>	Unreported	Comma-shaped	Oval-shaped	Unreported	Unreported	DSSM	1	Unreported	Unreported	Brožek et al., 2006
										Brožek and Bourgoïn, 2013b
<i>Proutista moesta</i>	Bifurcate cone-like	Semicircular	Oblong-shaped	BSN	4	CLSU	5	BSN	2	This study
<i>Proutista fritillaris</i>	Unreported	Unreported	Unreported	PGSU	4	DSSM	1	BSN	1	Brožek and Bourgoïn, 2013a
						PGSU	6			
						PPSU	1			

BSN, sensillum basiconica; CLSU, uniporous clavate-like sensillum; DSSM, multiporous dome-shaped sensillum; PGUSU, uniporous peg sensillum; PPSU, peg-in-pit uniporous sensillum; SF-D-A, flat field A of dorsal sensory field on the labial tip; SF-D-B, flat field B of dorsal sensory field on the labial tip; SF-V, ventral sensory field on the labial tip.



**Fig. 10.** Scheme of the labial tip and the distribution of the different apical sensilla of derbids. (A) View of labial tip of *D. politus*. (B) View of labial tip of *P. moesta*. Lg, labial groove; Nos. 1–4, sensilla basiconica subtype III on the field A of the dorsal sensory field; No. 5, multiporous dome-shaped sensillum on the field B of the dorsal sensory field; Nos. 6–10, uniporous clavate-like sensilla on the field B of the dorsal sensory field; Nos. 11–12, sensilla basiconica subtype III on the ventral sensory field. SF-D, dorsal sensory field; SF-D-A, field A of the dorsal sensory field; SF-D-B, field B of the dorsal sensory field; SF-V, ventral sensory field.



**Fig. 11.** SEM of the stylets of *D. politus*. (A) and (B) Cross-section of stylet fascicle showing mandibular stylets and maxillary stylets, the interlocking between the maxillary stylets, food canal, salivary canal, two dendritic canals in each maxillary stylet (white triangle) and one dendritic canal in each mandibular stylet (white star). (C) and (D) Whole stylet fascicle. (E) and (F) Apices of maxillary stylets showing the food canal, salivary canal and interlocking canal (white long triangle). (G) External surface of the apex of mandibular stylet. (H) Lateral view of the apex of mandibular stylet. (I) Smooth inner surface of mandibular stylet. Fc, food canal; LMd, left mandibular stylet; LMx, left maxillary stylet; Md, mandibular stylet(s); Mx, maxillary stylet(s); RMd, right mandibular stylet; RMx, right maxillary stylet; Sc, salivary canal; Sf, stylet fascicle. Scale bars: (A), (B), (E), (F), (H) and (I) = 5  $\mu$ m; (C) = 200  $\mu$ m; (D) = 150  $\mu$ m; (G) = 15  $\mu$ m.

approximately elliptical and the other is irregular, smaller than the dendritic canal of mandibular stylet (Fig. 7E).

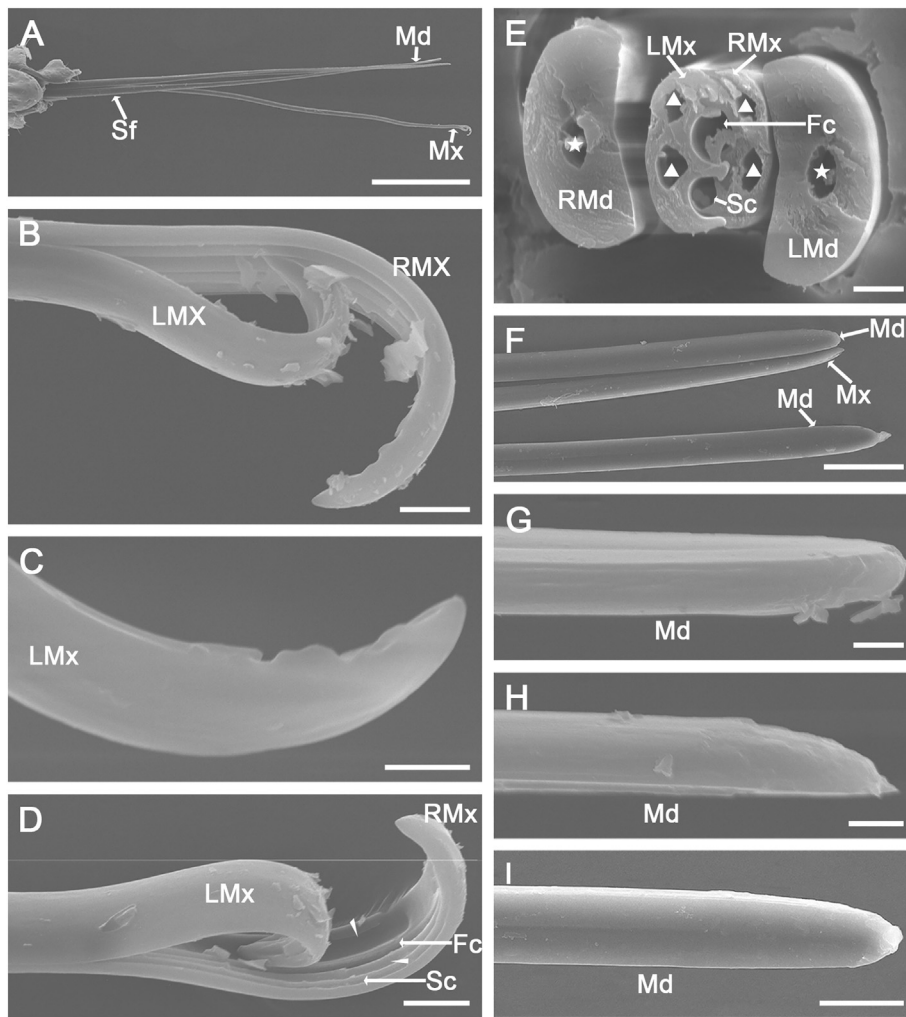
## Discussion

This study found *Diostrombus politus* (Fig. 11A, B) and *Proutista moesta* (Fig. 12E) have semicircular transverse sections of mandibular stylets, rather than being comma-shaped as in *D. gangumis* (Brožek et al., 2006, Figs. 8, 19; Brožek and Bourgoïn, 2013b, Figs. 7o, 9e). In addition, *D. politus* and *P. moesta* have an oblong-shaped cross-section of interlocking maxillary stylets, differing from the oval-shaped cross-section in *D. gangumis* (Table 3).

The paired subapical labial sensilla was first mentioned in delphacids by Sögawa (1977) and have subsequently been found in most fulgoromorphans (Liang, 2005; Brožek and Bourgoïn, 2013a; Hao et al., 2016; Meng and Qin, 2017). This shows more or less diversity across families in Fulgoroidea. In addition, in the Delphacidae, *Nilapavarta lugens* (Stål) has the sensillum possessing two major branches with 8–10 lobes (Sögawa, 1981; Foster et al., 1983b, Fig. 1a; Backus, 1985, Fig. 7.5 (b)); in *Sogatella furcifera* (Horváth), it only has 8–10 lobes (Dai et al., 2014, Fig. 5B, C). This study found

*P. moesta* has an elevated cone-like subapical labial sensillum (Fig. 8F); but in *D. politus*, it is bifurcate (Fig. 7F). Hence, we propose that the subapical labial sensilla are likely different among genera in the family Derbidae.

Brožek and Bourgoïn (2013a) divided Fulgoromorpha into two main groups based on the total number of sensilla at the tip of the labium. Derbidae was usually assigned to the first group (including Achilidae, Cixiidae, Delphacidae, Derbidae, Dictyopharidae, Issidae, Kinnaridae, Meenoplidae, Nogodinidae, Ricaniidae, Tettigometridae and Tropiduchidae which bear 24–38 sensilla) at the base of the phylogeny. Derbidae was further assigned to the cixiid pattern (including Achilidae, Cixiidae, Delphacidae, Derbidae, Dictyopharidae, Kinnaridae, Meenoplidae and Tettigometridae) based on the distribution of the apical labial sensilla (Brožek and Bourgoïn, 2013a). This study found the total number ( $N = 24$ ) of apical labial sensilla in these three derbid species is stable. In addition, two species in this study all have elevated cone-like subapical labial sensilla (Fig. 7F, 8F), Brožek and Bourgoïn (2013a) thought the cone-shaped or tubular subapical labial sensilla represent the plesiomorphic state in planthoppers. Thus, we think Derbidae might represent primitive group in Fulgoroidea.



**Fig. 12.** SEM of the stylets of *P. moesta*. (A) Whole stylet fascicle. (B) and (D) Two interlocking curving maxillary stylets showing the food canal, salivary canal and interlocking canals (white long triangle). (C) Smooth outer surface of the left maxillary stylets. (E) Cross-section of stylet fascicle showing mandibular stylets and maxillary stylets, the interlocking between the maxillary stylets, food canal, salivary canal, two dendritic canals in each maxillary stylet (white triangle) and one dendritic canal in each mandibular stylet (white star). (F) Tips of mandibular and maxillary stylets. (G) The smooth inner surface and the dull protuberances in mandibular stylet. (H) Lateral view of the mandibular stylet showing dull protuberances on the convex external surface. (I) Smooth inner surface of the mandibular stylet. Fc, food canal; LMd, left mandibular stylet; LMx, left maxillary stylet; Md, mandibular stylet(s); Mx, maxillary stylet(s); RMd, right mandibular stylet; RMx, right maxillary stylet; Sc, salivary canal; Sf, stylet fascicle. Scale bars: (A) = 200  $\mu\text{m}$ ; (B) and (D) = 5  $\mu\text{m}$ ; (C), (G), (E) and (C), (E), (G) and (H) = 2.5  $\mu\text{m}$ ; (F) = 25  $\mu\text{m}$ ; (I) = 10  $\mu\text{m}$ .

## Acknowledgements

The authors gratefully acknowledge Prof. John Richard Schrock (Emporia State University, Emporia, USA) for reviewing the early draft of this manuscript. This research was supported by the National Natural Science Foundation of China (grant number 31672340).

## References

- Ashe, J.J., 2000. Mouthpart structure of *Stylgymnusa subantarctica* Hammond, 1975 (Coleoptera: Staphylinidae: Aleocharinae) with a reanalysis of the phylogenetic position of the genus. *Zool. J. Linnean Soc.* 130, 471–498.
- Attíe, M., Bourgoïn, T., Veslo, J., Soulier-Perkins, A., 2008. Patterns of trophic relationships between planthoppers (Hemiptera: Fulgoromorpha) and their host plants on the Mascarene Islands. *J. Nat. Hist.* 42, 1591–1638.
- Backus, E.A., 1985. Anatomical and sensory mechanisms of leafhopper and planthopper feeding behavior. In: Nault, L.R., Rodriguez, J.G. (Eds.), *The Leafhoppers and Planthoppers*. Wiley-Interscience, New York, pp. 163–194.
- Beutel, R.G., Kristensen, N.P., Pohl, H., 2009. Resolving insect phylogeny: the significance of cephalic structures of the Nannomecoptera in understanding endopterygote relationships. *Arthropod Struct. Dev.* 38, 427–460.
- Bourgoïn, T., Wang, R.R., Asche, M., Hoch, H., Soulier-Perkins, A., Strojiński, A., Yap, S., Szewdo, J., 2015. From micropterism to hyperpterism: recognition strategy and standardized homology-driven terminology of the forewing venation patterns in planthoppers (Hemiptera: Fulgoromorpha). *Zoomorphology* 134, 63–77.
- Brožek, J., 2014. Phylogenetic signals from Nepomorpha (Insecta: Hemiptera: Heteroptera) mouthparts: stylets bundle, sense organs, and labial segments. *Sci. World J.* 2014, 237854.
- Brožek, J., Bourgoïn, T., 2013a. Morphology and distribution of the external labial sensilla in Fulgoromorpha (Insecta: Hemiptera). *Zoomorphology* 132, 33–65.
- Brožek, J., Bourgoïn, T., 2013b. The phylogenetic information carried by a new set of morphological characters in planthoppers: the internal mouthpart structures and test in the Cixiidae model (Hemiptera: Fulgoromorpha). *Zoomorphology* 132, 403–420.
- Brožek, J., Bourgoïn, T., Szewdo, J., 2006. The interlocking mechanism of maxillae and mandibles in Fulgoroidea (Insecta: Hemiptera: Fulgoromorpha). *Pol. J. Entomol.* 75, 239–253.
- Chapman, R.F., 2013. *The Insects: Structure and Function*, fifth ed. Cambridge University Press, Cambridge.
- Cobben, R.H., 1978. *Evolutionary Trends in Heteroptera. Part II. Mouthpart-Structures and Feeding Strategies*. Mededlingen Landbouwhoghe School, Wageningen.
- Dai, W., Pan, L.X., Lu, Y.P., Jin, L., Zhang, C.N., 2014. External morphology of the mouthparts of the whitebacked planthopper *Sogatella furcifera* (Hemiptera: Delphacidae), with special reference to the sensilla. *Micron* 56, 8–16.
- Forbes, A.R., 1977. The mouthparts and feeding mechanism of aphids. In: Harris, K.F., Maramorosch, K. (Eds.), *Aphids as Virus Vectors*. Academic Press, New York, pp. 83–103.
- Foster, S., Goodman, L.J., Duckett, J.G., 1983a. Sensory receptors associated with the stylets and cibarium of the rice brown planthopper, *Nilaparvata lugens*. *Cell Tissue Res.* 232, 111–119.
- Foster, S., Goodman, L.J., Duckett, J.G., 1983b. Ultrastructure of sensory receptors on the labium of the rice brown planthopper. *Cell Tissue Res.* 230, 353–366.
- Hao, Y.N., Dietrich, C.H., Dai, W., 2016. Structure and sensilla of the mouthparts of the spotted lanternfly *Lycorma delicatula* (Hemiptera: Fulgoromorpha: Fulgoridae), a polyphagous invasive planthopper. *PLoS One* 11, e0156640.
- Jameson, M.L., Mico, E., Galante, E., 2007. Evolution and phylogeny of the scarab subtribe Anisopliina (Coleoptera: Scarabaeidae: Rutelinae: Anomalini). *Syst. Entomol.* 32, 429–449.
- Krenn, H.W., 2007. Evidence from mouthpart structure on interordinal relationships in Endopterygota? *Arthropod Syst. Phylon.* 65, 7–14.
- Labandeira, C.C., 1997. Insect mouthparts: ascertaining the paleobiology of insect feeding strategies. *Annu. Rev. Ecol. Syst.* 28, 153–193.
- Lee, I.M., Davis, R.E., Gundersen-Rindal, D.E., 2000. Phytoplasmas: phytopathogenic mollicutes. *Annu. Rev. Microbiol.* 54, 221–255.
- Liang, A.P., 2001. Morphology of antennal sensilla in *Achilixius sandakanensis* Muir (Hemiptera: Fulgoromorpha: Achilixiidae) with comments on the phylogenetic position of the Achilixiidae. *Raffles B. Zool.* 49, 221–225.
- Liang, A.P., 2005. Occurrence of the latero-subapical labial sensillum in *Borysthene maculata* and *Andes marmorata* (Hemiptera: Fulgoromorpha: Cixiidae). *J. Entomol. Sci.* 40, 428–437.

- Meier, R., Lim, G.S., 2009. Conflict, convergent evolution, and the relative importance of immature and adult characters in endopterygote phylogenetics. *Annu. Rev. Entomol.* 54, 85–104.
- Meng, Y.F., Qin, D.Z., 2017. Fine morphology of the antennae and mouthparts of *Dentatissus damnosa* (Chou & Lu) (Hemiptera: Issidae). *Zool. Anz.* 268, 64–74.
- Mora, R., Retana, A., Espinoza, A.M., 2001. External morphology of *Tagosodes orizicolus* (Homoptera: Delphacidae) revealed by scanning electron microscopy. *Ann. Entomol. Soc. Am.* 94, 438–448.
- O'Brien, L.B., Wilson, S.W., 1985. Planthopper systematics and external morphology. In: Nault, L.R., Rodriguez, J.G. (Eds.), *The Leafhoppers and Planthoppers*. Wiley, New York, pp. 61–102.
- Schneider, D., 1964. Insect antennae. *Annu. Rev. Entomol.* 9, 103–122.
- Scholtz, C.H., 1990. Phylogenetic trends in the Scarabaeoidea (Coleoptera). *J. Nat. Hist.* 24, 1027–1066.
- Sinclair, B.J., 1992. A phylogenetic interpretation of the Brachycera (Diptera) based on the larval mandible and associated mouthpart structures. *Syst. Entomol.* 17, 233–252.
- Sōgawa, K., 1977. Feeding physiology of the brown planthopper. In: *The Rice Brown Planthopper. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei*, pp. 95–114.
- Sōgawa, K., 1981. Scanning electron microscopy of the labial tip, feeding mark, and stylet sheath of the brown planthopper. *Proc. Assoc. Plant Prot. Hokuriku* 29, 32–35.
- Wang, R.R., Wan, X.Y., Liang, A.P., Bourgoïn, T., 2012. Ultrastructure of sensory equipments on the heads of *Kallitaxila granulata* (Stål) (Hemiptera: Fulgoromorpha: Tropiduchidae). *Microsc. Res. Tech.* 75, 1659–1665.
- Weirauch, C., 2008. From four- to three-segmented labium in Reduviidae (Hemiptera: Heteroptera). *Acta Ent. Mus. Nat. Pra.* 48, 331–344.
- Yap, S.A., Bourgoïn, T., 2016. A new species of genus *Ceropupa* from Luzon, Philippines (Hemiptera: Derbidae: Sikaianini), with a key to the species of *Ceropupa* Emeljanov, 1996. *Halteres* 7, 157–162.
- Yap, S.A., Bourgoïn, T., Szewdo, J., Soulier-Perkins, A., Fernando, E.S., Gruezo, W.S., Pampolina, N.M., 2015. Planthopper-Palm relationships: The case of the Sikaianini (Hemiptera: Fulgoroidea: Derbidae). In: *Abstracts of Talks and Posters, 7th European Hemiptera Congress and 9th International Workshop on Leafhoppers and Planthoppers of Economic Importance*, Graz, Austria, pp. 88.
- Zacharuk, R.Y., 1985. Antennae and sensilla. In: Kerkut, G.A., Gilbert, L.I. (Eds.), *Comprehensive Insect Physiology, Biochemistry and Pharmacology*. Vol. 6. Pergamon Press, Oxford, pp. 1–69.
- Zhang, Y.L., Peng, L.F., Wang, Y.L., 2011. *Nivalios* gen. nov. (Hemiptera: Fulgoromorpha: Flatidae), first record of the tribe Nephesini from China. *Zootaxa* 2882, 19–26.