



A taxonomic revision of the genus *Goniogryllus* in China (Orthoptera: Gryllidae: Gryllinae)

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Abstract

Species belonging to the genus *Goniogryllus* Chopard, 1936 are primarily identified based on their morphological characteristics. However, male genitalia provide limited features for classification. In this study, we sequenced the COI gene from 49 samples, and reconstructed a phylogenetic tree. Species were classified by a combination of molecular and morphological data, and some morphological features were re-evaluated. The results indicate that the presence or absence of pubescence on the thorax and abdomen, yellow stripes on the head with or without bifurcation, and the color of the maxillary palpus are interspecific differences. The classification based on these morphological features are consistent with the classification based on COI gene. In contrast, variations in the color of the hind femur, pronotum, and the number of dorsal spurs on the hind tibia are considered to be intraspecific variations. Additionally, *Qingryllus striofemorus* Chen & Zheng, 1995 and *Q. jiguanshanensis* Liu, Zhang & Shi, 2017 are recognized as the long-wing forms of *G. ovalatus* Chen & Zheng, 1996. Therefore, *Qingryllus* Chen & Zheng, 1995 **syn.** is a junior synonym of *Goniogryllus*. *Q. striofemorus* **syn. nov.** and *Q. jiguanshanensis* **syn. nov.** are junior synonyms of *G. ovalatus*. Furthermore, *G. cirilinearis* Xie, 2005 **syn. nov.** is a junior synonym of *G. atripalpus* Chen & Zheng, 1996. *G. octospinatus* Chen & Zheng, 1995 **syn. nov.** is a junior synonym of *G. chongqingensis* Chen & Zheng, 1995. Lastly, *Callogryllus yunnanus* Wu & Zheng, 1992 is transferred to the genus *Goniogryllus*, as *Goniogryllus yunnanus* **comb. nov.**

Keywords

COI, morphology, *Qingryllus*, taxonomy

1. Introduction

The genus *Goniogryllus* Chopard, 1936 belongs to Gryllinae, Gryllidae, Orthoptera. It was established by Chopard in 1936, with *G. punctatus* Chopard, 1936 from Fujian, China as the type species. Prior to this study, there were 21 species reported from Japan, Assam, and China with 19 species from China (Chopard 1936; Bey-Bienko 1956; Chopard 1969; Ichikawa 1987; Wu and Wang 1992; Chen

and Zheng 1995a, 1995b, 1996; Xie and Zheng 2003; Xie and Ou 2005; Xie 2005; Xie et al. 2006; Cigliano et al. 2023). Compared with other Gryllinae species, *Goniogryllus* species are characterized by yellow stripes extending from occiput, along the eyes to the lateral ocelli; no wings or scaly wings; no tympanum on the fore tibia (Chopard 1969; Wu and Wang 1992; Xie et al. 2006).

Goniogryllus is primarily identified based on morphological features, such as the presence or absence of pubescence on the thorax and abdomen, yellow stripes on the head with or without bifurcation, the color of the maxillary palpus, hind femur or pronotum, and the number of dorsal spurs on the hind tibia (Chopard 1936; Wu and Wang 1992; Chen and Zheng 1995b, 1996). However, some species possess similar morphological features with only minor differences. For example, there is no significant morphological difference between *G. cirilinearis* Xie, 2005 and *G. atripalpus* Chen & Zheng, 1996 (both species have four yellow-brown spots on the 2th to 8th segments of the abdomen). The only difference mentioned by Xie (2005) is that *G. cirilinearis* has two short reddish-brown stripes on its occiput, whereas *G. atripalpus* does not. Additionally, over half of the species (11 species) have been published with only holotype specimens, which is higher than the 21.53% reported in other insects (Deng et al. 2019). Consequently, further revision of the taxonomy of *Goniogryllus* is needed.

The genus *Qingryllus* Chen & Zheng, 1995 also belongs to Gryllinae, and its type species, *Q. striofemorus* Chen & Zheng, 1995, is collected from Xunyangba and Huoditang, Ningshan, Shaanxi, which are also the collecting sites for the holotype of *G. ovalatus* Chen & Zheng, 1996 and *G. atripalpus* (Chen and Zheng 1995a, 1996). These two genera share a similar appearance, both possessing a pair of yellow-brown longitudinal stripes on each side of the head, and lacking a tympanum on the fore tibia. The main difference lies in the fully developed forewings and hindwings of *Qingryllus*, while those of *Goniogryllus* are either underdeveloped or apterous (Chen and Zheng 1995a; Liu et al. 2017).

He (2018) compared sequences of the COI gene of *G. ovalatus* and *Q. striofemorus*, and found them to be identical. He (2018) suggested that *Qingryllus* is a junior synonym of *Goniogryllus*, but did not make further revisions. Yang et al. (2019) resurrected *Qingryllus* as a valid genus, because they considered that species of “two genera had different habitus and habitats”. However, they did not provide additional evidence.

The holotype of *Callogryllus yunnanus* Wu & Zheng, 1992 was collected from Yunnan, China. It bears a resemblance to the above two genera. The unique feature of this species is the presence of a pair of short forewing with irregular veins in males. Wu and Zheng (1992) placed this species in the genus *Callogryllus* Sjöstedt, 1910, likely due to its morphological similarities to *Callogryllus* species from India. However, they did not study the morphology of male genitalia. In fact, *C. yunnanus* in females lack wings, which is very similar to *Goniogryllus* species, and males are also very similar if its forewing are not considered as its features.

To clarify the relationship among partial *Goniogryllus*, *Qingryllus* and *C. yunnanus*, and to revise partial species in the genus *Goniogryllus*, we reconstructed a phylogenetic tree based on molecular markers (COI gene) and estimated the number of molecular operational taxonomic units (MOTUs) by three methods, Automatic Barcode Gap Discovery (ABGD), Assemble Species by Automat-

ic Partitioning (ASAP), and Bayesian Poisson Tree Processes (bPTP). We also combined it with morphological classification to evaluate these morphological features.

2. Material and methods

2.1. Sampling

The specimens were collected by hand. Photomicrographs were taken by SC2000 digital CMOS Camera, and edited by using Adobe Photoshop. A total of 49 individuals belonging to *Goniogryllus*, *Qingryllus* and *C. yunnanus* were examined for this study. All specimens are preserved in the Biological History Museum of East China Normal University (ECNU).

2.2. Measurements

The measurements and indices taken are defined below: **BL** – body length, length from the apex of fastigium verticis to the apex of subgenital plate; **SZ** – body size, length from the apex of fastigium verticis to the end of hindwing (for *Qingryllus* only); **PL** – pronotum length, length from anterior margin to posterior margin; **FWL** – forewing length, length from the base of forewing to the apex; **HWL** – hindwing length, length from the base of hindwing to the apex; **HFL** – hind femur length, maximum distance from the base of hind femur to the apex; **OL** – ovipositor length, straight line distance from the base of ovipositor to the apex.

2.3. Morphological terminology

The terminology used to describe male genitalia followed Gorochoy (2015).

2.4. DNA extraction and amplification

The total genomic DNA was extracted from the muscles of one hind leg by AxyPrep Genomic DNA Miniprep Kit (AXYGEN), according to the manufacturer's instructions. The fragments of the mitochondrial cytochrome-c oxidase subunit I gene (COI, 658 bp) were sequenced by primers COBU TYTCAACAAAYCAYAARGATATTGG and COBL TAAACTTCWGGRTGWCCAAARAATCA (Pan et al. 2006). Primers LCO-1490 GGTCACAAAT-CATAAAGATATTGG and HCO-2198 TAAACTTCAG-GGT GACCAAAAAATCA were used when the first pair of primers did not work (Folmer et al. 1994). Parameters for PCR were as follow: pre-denaturation for 5 mins at 94°C, 30 cycles of 30 s at 94°C, 30 s at 45°C, then 30 s at 72°C, and a final extension at 72°C for 5 mins. GenBank accession numbers are shown in Table 1.

Table 1. Collecting information and COI GenBank accession number.

Genus	Species	No.	voucher	Collection site	GenBank
<i>Goniogryllus</i>	<i>punctatus</i>	1	H174	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102820
		2	225	Zhejiang, Hangzhou, Qingliangfeng Nature Reserve	OR102795
		3	312	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102798
		4	348	Zhejiang, Hangzhou, Qingliangfeng Nature Reserve	OR102803
		5	523	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102829
		6	542	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102816
		7	632	Zhejiang, Hangzhou, Qingliangfeng Nature Reserve	OR102817
		8	1106	Zhejiang, Hangzhou, Qingliangfeng Nature Reserve	OR102785
		9	2531	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102796
		10	2532	Zhejiang, Hangzhou, Tianmushan Nature Reserve	OR102797
	<i>emeicus</i>	1	675	Sichuan, Emeishan, Emeishan	OR102818
		2	679	Sichuan, Emeishan, Emeishan	OR102819
		3	1972	Sichuan, Emeishan, Emeishan	OR102787
		4	1982	Sichuan, Emeishan, Emeishan	OR102792
	<i>chongqingensis</i>	1	3440	Chongqing, Beibei, Jinyunshan	OR102799
		2	3441	Chongqing, Beibei, Jinyunshan	OR102800
	<i>octospinatus</i>	1	4551	Hubei, Lichuan, Fubaoshan	OR102802
		2	4554	Hubei, Lichuan, Fubaoshan	OR102801
	<i>cirilinearis</i>	1	4535	Shaanxi, Lan'gao, Dabashan	OR102805
		2	4536	Shaanxi, Lan'gao, Dabashan	OR102824
		3	4539	Shaanxi, Lan'gao, Dabashan	OR102807
	<i>atripalpus</i>	1	4547	Hubei, Danjiangkou, Wudangshan	OR102811
		2	4548	Hubei, Danjiangkou, Wudangshan	OR102812
	<i>glaber</i>	1	1974	Yunnan, Lushui, Pianma	OR102788
		2	1976	Yunnan, Lushui, Pianma	OR102789
	<i>ovalatus</i>	1	H007	Shaanxi, Ningshan, Huoditang	OR102821
		2	H008	Shaanxi, Ningshan, Huoditang	OR102822
		3	1921	Shaanxi, Huayang, Changqing Nature Reserve	OR102786
		4	1981	Sichuan, Emeishan, Emeishan	OR102791
		5	1986	Sichuan, Emeishan, Emeishan	OR102793
		6	1989	Sichuan, Emeishan, Emeishan	OR102794
		7	4532	Sichuan, Maoxian, Jiudingshan	OR102804
		8	4537	Gansu, Zhouqu, Wuping	OR102806
		9	4542	Chongqing, Wushan, Lizingping	OR102809
		10	4545	Hubei, Wufeng, Houhe Nature Reserve	OR102810
		11	4550	Hubei, Lichuan, Fubaoshan	OR102828
		12	4552	Hubei, Lichuan, Fubaoshan	OR102814
		13	4555	Hubei, Lichuan, Fubaoshan	OR102827
		14	4556	Hubei, Lichuan, Fubaoshan	OR102815
		15	4558	Hubei, Lichuan, Fubaoshan	OR102825
		16	4559	Hubei, Lichuan, Fubaoshan	OR102826
<i>Qingryllus</i>	<i>jiguanshanensis</i>	1	1980	Sichuan, Emeishan, Emeishan	OR102790
	<i>striofemorus</i>	1	3882	Hubei, Shennongjia, Songbai	OR102830
		2	4540	Shaanxi, Langao, Dabashan	OR102808
		3	4549	Hubei, Lichuan, Fubaoshan	OR102813
		4	4671	Shaanxi, Ningshan, Huoditang	OR102823
<i>Callogryllus</i>	<i>yunnanus</i>	1	4224	Yunnan, Yuxi, Ailaoshan	PP967855
		2	4226	Yunnan, Yuxi, Ailaoshan	PP967856
		3	4228	Yunnan, Yuxi, Ailaoshan	PP967857

2.5. Molecular analyses

A total of 49 COI sequences were obtained from samples of *Goniogryllus*, *Qingryllus* and *C. yunnanus*, which were used for molecular analysis. The COI sequence of

Paratrigonidium nitidum Brunner von Wattenwyl, 1893 was used as the outgroup. Additionally, the COI gene of 47 individuals from the Gryllini group were included to assess the monophyly of *Goniogryllus* (see Table S1 for details). All sequences were aligned in MEGA X follow-

Table 2. Diagnosis for *Goniogryllus* species in this study (*G. ovalatus* with fully developed wings not included).

Feature	<i>G. ovalatus</i>		<i>G. atripalpus</i>		<i>G. chongqingensis</i>		<i>G. punctatus</i>		<i>G. emeicus</i>		<i>G. glaber</i>	<i>G. yunnanus</i>	
	10♀	9♂	3♀	2♂	3♀	1♂	4♀	2♂	2♀	2♂	2♂	2♀	1♂
Pronotum pubescent	Yes		No		No		No		No		No	No	
♀ Abdomen pubescent	Yes		Yes		No		No		No		/	No	
♂ The first three segments of abdomen pubescent	Yes		Yes		No		No		No		No	No	
Yellow stripes on the head bifurcated	No		Yes		No		Yes		No		No	No	
Maxillary palpus black	No		Yes		No		Yes		No		Yes	No	
Apical part of epiphallus with process	Yes		No		Yes		Yes		Yes		/	/	

ing MUSCLE method. We used DAMBE to conduct the saturation test (Xia et al. 2003; Xia and Lemey 2009). Iss is significantly lower than Iss.c (Iss = 0.188; Iss.c = 0.805; $p < 0.05$), suggesting little saturation. Maximum likelihood (ML) tree was conducted using the TM2+I+F model strategy in IQ-TREE with 1000 ultrafast bootstrap replicates (Minh et al. 2013; Nguyen et al. 2015). The tree was also tested with approximate Bayes test (Anisimova et al. 2011), as well as the Shimodaira-Hasegawa-like approximate likelihood-ratio test (Guindon et al. 2010). To estimate the number of molecular operational taxonomic units (MOTUs), three methods were employed: Automatic Barcode Gap Discovery (ABGD), Assemble Species by Automatic Partitioning (ASAP), and Bayesian Poisson Tree Processes (bPTP). The ABGD analysis was conducted online (<https://bioinfo.mnhn.fr/abi/public/abgd/abgdweb.html>) with the default settings, using a relative gap width ($X = 1.2$) and intraspecific divergence (P) values between 0.001 and 0.100 with the K2P model (Puillandre et al. 2012). The ASAP analysis was performed using web browser (<https://bioinfo.mnhn.fr/abi/public/asap/>) with the Jukes-Cantor (JC69) model and default settings (Puillandre et al. 2021). The bPTP analysis was run on the web server (<http://species.h-its.org/ptp>) with 100,000 MCMC generations and default parameters (Zhang et al. 2013).

3. Results

3.1. Molecular study

When using *P. nitidum* as the outgroup, a strong clade consisting of 49 individuals from *Goniogryllus*, *Qingryllus*, and *C. yunnanus* was formed, with 7 subclades identified by ABGD and ASAP analysis. The first subclade includes *C. yunnanus* only. The second subclade consists of *G. glaber* Wu & Wang, 1992 only. The third subclade includes *G. atripalpus* and *G. cirilinearis*. The fourth subclade includes *G. chongqingensis* Chen & Zheng, 1995 and *G. octospinatus* Chen & Zheng, 1995. The fifth subclade includes *G. ovalatus*, *Q. striofemorus*, and *Q. jiguanshanensis* Liu, Zhang & Shi, 2017. The

sixth subclade consists of *G. emeicus* Wu & Wang, 1992 only. The seventh subclade comprises *G. punctatus* only (Fig. 1). The result from bPTP analysis also demonstrated a similar delimitation, although it grouped *G. punctatus* and *G. emeicus* as a single operational taxonomic unit.

3.2. Systematics

Class Insecta Linnaeus, 1758

Order Orthoptera Latreille, 1810

Family Gryllidae Laicharting, 1781

Subfamily Gryllinae Laicharting, 1781

Genus *Goniogryllus* Chopard, 1936

Goniogryllus Chopard 1936: 7; Chopard 1967: 118; Ichikawa 1987: 8; Wu and Wang 1992: 231; Yin and Liu 1995: 191; Chen and Zheng 1995: 213–217; Ichikawa and Honda 2000: 261; He 2018: 529; Yang et al. 2019: 16.

Qingryllus **syn.** (synonymized by He 2018, resurrected by Yang et al. 2019) Chen and Zheng 1995: 70, 75; Liu et al. 2017: 65–70; He 2018: 529; Yang et al. 2019: 20.

Type species. *Goniogryllus punctatus* Chopard, 1936.

Diagnosis. Average size; black head with yellow stripes extending from occiput, along eyes to lateral ocelli, the yellow stripes divided into two branches from the middle of eyes or no bifurcation; maxillary palpus all black or with yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint; pronotum all black or with yellow spots or stripes on both sides, glabrous or pubescent; no wings, scaly wings, short wings, or fully developed wings; abdomen glabrous or pubescent; long ovipositor.

Remarks. The molecular analysis reveals that *G. ovalatus*, *Q. striofemorus*, and *Q. jiguanshanensis* form a cohesive clade with strong support. Morphologically,

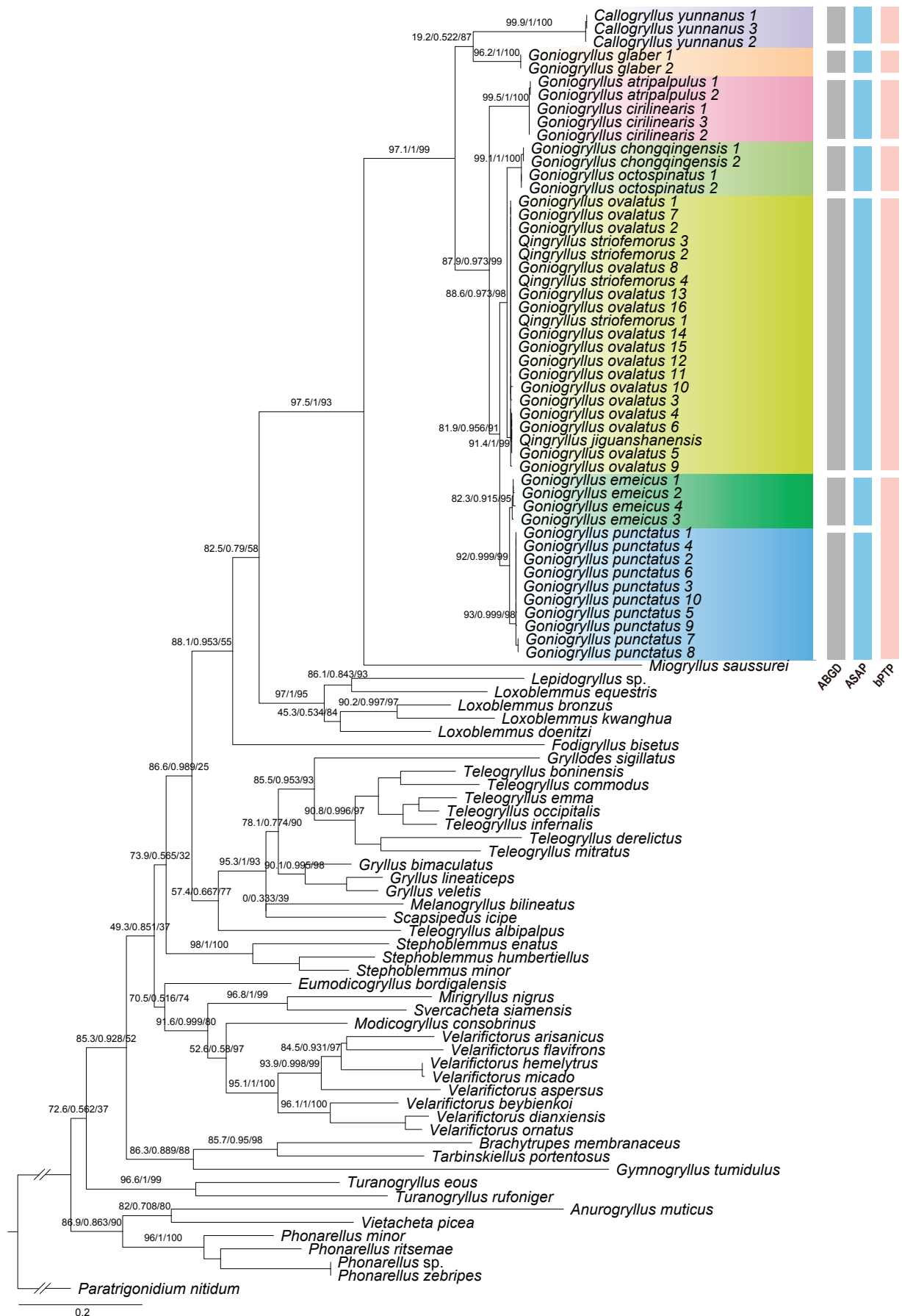


Figure 1. The relationship among partial *Goniogryllus*, *Qingryllus* and *C. yunnanus* species was inferred from the COI gene. Rooted by *P. nitidum*, the tree was constructed by Maximum likelihood (ML) with TIM2+I+F model. Topology supports of all major nodes were indicated above branches in this order: the SH-aLRT value, the Bayesian posterior probability and the bootstrap value. The MOTUs was shown by color bars based on ABGD, ASAP, and bPTP analysis in grey, blue, and pink respectively.

they share similarities such as processing a pair of yellow-brown longitudinal stripes on each side of the head, and the absence of a tympanum on the fore tibia. Moreover, their male genitalia exhibit resemblances. They are often found in the same collection sites (Fig. 2). Based on these findings, we conclude that *Q. striofemorus* and *Q. jiguanshanensis* are the long-wing forms of *G. ovalatus*. We treat *Qingryllus* **syn.** as a junior synonym of *Goniogryllus*. Additional information can be found in the diagnosis of *G. ovalatus*. A diagnosis for species is provided in Table 2.

Goniogryllus ovalatus Chen & Zheng, 1996

Goniogryllus ovalatus Chen & Zheng 1996: 290, 293; He 2018: 529; Yang et al. 2019: 16; Zhao and Liu 2022: 244.

Qingryllus striofemorus **syn. nov.** Chen & Zheng 1995: 70, 76; Zhao and Liu 2022: 246; Liu et al. 2017: 67; He 2018: 529.

Qingryllus jiguanshanensis **syn. nov.** Liu et al. 2017: 67; He 2018: 518; Zhao and Liu 2022: 246.

Material examined. *G. ovalatus*: CHINA • ♂ (1921); Shaanxi Prov., Hanzhong City, Huayang Town, Changqing Nature Reserve (107°33'E, 33°35'N); 8 May. 2019; Zhao-Yang Chen leg. (ECNU). CHINA • 1♂2♀ (1981, 1986, 1989); Sichuan Prov., Leshan City, Emeishan County, Emeishan (103°21'E, 29°34'N); 20 Jun. 2018; Wen-Xuan Bi leg. (ECNU). CHINA • ♂ (4532); Sichuan Prov., Mao County, Jiuding-shan (103°44'E, 31°31'N); 3 Jun. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♀ (4537); Gansu Prov., Zhouqu County, Wuping Town (104°20'E, 33°37'N); 6 Jun. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♂ (4542); Chongqing City, Wushan County, Luoping Town, Liziping Forest Park (109°58'E, 31°13'N); 23 May. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♀ (4545); Hubei Prov., Yichang City, Wufeng County, Houhe Nature Reserve (110°36'E, 30°12'N); 25 Jun. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • 4♂2♀ (4550, 4552, 4555, 4556, 4558, 4559); Hubei Prov., Lichuan City, Wangying Town, Fubaoshan (108°44'E, 30°11'N); 19 May. 2021; Wen-Xuan Bi leg. (ECNU). — *G. ovalatus* (= *Q. striofemorus*): CHINA • ♀ (3882); Hubei Prov., Shennongjia Forest, Songbai Town (110°40'E, 31°45'N); 27 May. 2021; Zi-Hao Shen leg. (ECNU). CHINA • ♀ (4540); Shaanxi Prov., Ankang City, Langao County, Dabashan (108°54'E, 32°18'N); 15 Jun. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♂ (4549); Hubei Prov., Lichuan City, Wangying Town, Fubaoshan (108°44'E, 30°11'N); 19 May. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♀ (4671); Shaanxi Prov., Ankang City, Ningshan County, Huoditang Village (108°27'E, 33°26'N); 11 Jun. 2000; Kai Li leg. (ECNU). — *G. ovalatus* (= *Q. jiguanshanensis*): CHINA • ♀ (1980); Sichuan Prov., Leshan City, Emeishan County, Emeishan (103°21'E, 29°34'N); 20 Jun. 2018; Wen-Xuan Bi leg. (ECNU).

Diagnosis. No wings, scaly wings, or fully developed wings; pronotum pubescent, if no wings or scaly wings, mesonotum and metanotum pubescent, abdomen pubescent in females, but only the first three segments of abdomen pubescent in males, if fully developed wings, mesonotum, metanotum and abdomen glabrous (Fig. 3A–C); yellow stripes on head without bifurcation (Fig. 4A–C); maxillary palpus black with yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint (Fig. 5A–C);

male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes prominent (Fig. 6C, D).

Remarks. *Qingryllus* contains two species, *Q. striofemorus* and *Q. jiguanshanensis* based on the width of the posterior margin of pronotum and the color of veins of tegmina (Fig. 3B, C; Liu et al. 2017). Based on these features, we temporally classified our samples as different “species”, but sequences of the COI gene of these “species” were almost the same. Moreover, *G. ovalatus* individuals were sometimes found in the same habitat as *Q. striofemorus* (HZQ personal observation). Thus, we consider *Q. striofemorus* **syn. nov.** and *Q. jiguanshanensis* **syn. nov.** as junior synonyms of *G. ovalatus*.

Measurements. (mm) ♂: BL 12.28–12.93; SZ 16.97–18.04; PL 2.23–2.65; FWL 9.54; HWL 13.27; HFL 6.83–7.57. — ♀: BL 11.44–13.65; SZ 17.50–17.95; PL 2.34–2.59; FWL 8.4–9.93; HWL 13.70–14.75; HFL 7.49–8.39; OL 9.17–9.94.

Distribution. China (Chongqing, Gansu, Hubei, Shaanxi, Sichuan).

Goniogryllus atripalpus Chen & Zheng, 1996

Goniogryllus atripalpus Chen & Zheng 1996: 289, 292; He 2018: 518; Yang et al. 2019: 16; Zhao and Liu 2022: 244.

Goniogryllus cirilinearis **syn. nov.** Xie 2005: 79–86; He 2018: 518; Zhao and Liu 2022: 244.

Material examined. *G. atripalpus*: CHINA • 1♀1♂ (4547, 4548); Hubei Prov., Shiyan City, Danjiangkou County, Wudangshan (111°04'E, 32°28'N); 19 Jun. 2021; Wen-Xuan Bi leg. (ECNU). — *G. atripalpus* (= *G. cirilinearis*): CHINA • 1♀1♂ (4535, 4536); Shaanxi Prov., Ankang City, Langao County, Dabashan (108°54'E, 32°18'N); 13 Jun. 2021; Wen-Xuan Bi leg. (ECNU). CHINA • ♀ (4539); Shaanxi Prov., Ankang City, Langao County, Dabashan (108°54'E, 32°18'N); 15 Jun. 2021; Wen-Xuan Bi leg. (ECNU).

Diagnosis. Apterous; mesonotum and metanotum pubescent slightly, abdomen pubescent slightly in females, but only the first three segments of abdomen pubescent slightly in males (Fig. 3D, E); yellow stripes extending from occiput, along eyes to lateral ocelli, the yellow stripes divided into two branches from the middle of eyes (Fig. 4I, J); maxillary palpus black (Fig. 5H, I); male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes without process (Fig. 6E, F); abdomen: female with four yellow-brown spots on the 2 to 8 segments, but black in males (Fig. 3D, E).

Remarks. The main difference between *G. cirilinearis* and *G. atripalpus* is: the occiput of *G. cirilinearis* is ornamented by two short reddish-brown stripes, while that of *G. atripalpus* is not (Xie 2005). However, the molecular result indicates that they are the same species. They all possess the above morphological features

in diagnosis. Besides, the length and width of stripes on occiput are varied in our study (Fig. 3D, E). Thus, we regard the short reddish-brown stripes as infraspecific variations in this species. Therefore, we place *G. cirilinearis* **syn. nov.** in a junior synonym of *G. atripalpus*.

Measurements. (mm) ♂: BL 13.84–14.89; PL 2.79–3.71; HFL 7.93–9.04. — ♀: BL 14.11–15.66; PL 3.14–3.71; HFL 9.37–9.75; OL 11.34–11.79.

Distribution. China (Gansu, Hubei, Shaanxi).

Goniogryllus chongqingensis Chen & Zheng, 1995

Goniogryllus chongqingensis Chen & Zheng 1995: 213, 216; Chen and Zheng 1996: 291; He 2018: 518; Zhao and Liu 2022: 244.

Goniogryllus octospinatus **syn. nov.** Chen & Zheng 1995: 215; Han et al. 2015: 21; He 2018: 518; Zhao and Liu 2022: 244.

Material examined. *G. chongqingensis*: CHINA • 2♀ (3440, 3441); Chongqing City, Beibei District, Jinyunshan (106°23'E 29°50'N); 19 Aug. 2020; Hui-Cong Xie leg. (ECNU). — *G. chongqingensis* (= *G. octospinatus*): CHINA • 1♂1♀ (4551, 4554); Hubei Prov., Lichuan City, Wangying Town, Fubaoshan (108°44'E 30°11'N); 19 May. 2021; Wen-Xuan Bi leg. (ECNU).

Diagnosis. Apterous; all glabrous (Fig. 3F, G); yellow stripes on the head without bifurcation (Fig. 4D, E); maxillary palpus black with yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint (Fig. 5D, E); male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes prominent (Fig. 6G). *G. chongqingensis* is similar to *G. emeicus* by Chen & Zheng, 1995. The difference is that *G. chongqingensis* is larger than *G. emeicus* in body size, and there is a finger-like process on the base fusion of endoparameron of *G. chongqingensis* (Chen and Zheng 1995b).

Remarks. The main difference between *G. chongqingensis* and *G. octospinatus* is: the pronotum and the hind femur of *G. chongqingensis* are black, while there are yellow stripes on both sides of pronotum and a yellow longitudinal stripe on the superior border of the hind femur of *G. octospinatus* (Chen and Zheng 1995b). However, the molecular result indicates that they are the same species. They all possess the above morphological features in diagnosis. See details for discussion about the color and pattern of the pronotum and hind femur as intraspecific variations (Fig. 7, 8). Therefore, we place *G. octospinatus* **syn. nov.** in a junior synonym of *G. chongqingensis*.

Measurements. (mm) ♂: BL 12.13; PL 2.57; HFL 7.04. — ♀: BL 12.24–13.82; PL 3.24–3.66; HFL 8.27–8.56; OL 9.40–10.99.

Distribution. China (Chongqing, Hubei, Sichuan).

Goniogryllus yunnanus (Wu & Zheng, 1992)

Callogryllus yunnanus **comb. nov.** Wu & Zheng 1992: 95; Yin and Liu 1995: 45; He 2018: 518; Zhao and Liu 2022: 244.

Material examined. CHINA • 1♂2♀ (4224, 4226, 4228); Yunnan Prov., Yuxi City, Xiping County, Ailaoshan (101°26'E 23°58'N); 16 Jul. 2021; Zhu-Qing He leg. (ECNU).

Diagnosis. No wings in females, wings short to the third segment of abdomen in males; all glabrous (Fig. 3K); yellow stripes on head without bifurcation (Fig. 4H); maxillary palpus black with yellow stripes on the dorsal side of the 5th joint (Fig. 5G); male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes strongly concave (Fig. 6B).

Remarks. The molecular result shows that *C. yunnanus* and *Goniogryllus* are in the same clade. *C. yunnanus* and *Goniogryllus* possess some of the same morphological features such as yellow stripes on each side of the head (Wu and Zheng 1992). Besides, the male genitalia of *C. yunnanus* and *Goniogryllus* are similar, they differ only in the degree of emargination on the inside of epiphallus. Combining molecular result and structures of genitalia, we consider *C. yunnanus* has close relationship with *Goniogryllus* rather than *Callogryllus kilimandjarius* Sjöstedt, 1910, the type species, from Africa. Thus, *Callogryllus yunnanus* Wu & Zheng, 1992 is transferred to the genus *Goniogryllus*, as *Goniogryllus yunnanus* **comb. nov.**

Measurements. (mm) ♂: BL 9.54; PL 2.38; FWL 2.13; HFL 5.83. — ♀: BL 9.58–10.21; PL 2.45–2.52; HFL 6.94–7.30; OL 8.57–8.96.

Distribution. China (Yunnan).

Goniogryllus punctatus Chopard, 1936

Goniogryllus punctatus Chopard 1936: 7; Yin and Liu 1995: 191; Gu and Huang 2018: 10; He 2018: 515–535; Zhao and Liu 2022: 244.

Material examined. CHINA • ♀ (312); Zhejiang Prov., Hangzhou City, Lin'an District, Tianmushan Nature Reserve (119°27'E, 30°20'N); 22 Aug. 2016; Jia-Yao Hu leg. (ECNU). — CHINA • ♀ (523); Zhejiang Prov., Hangzhou City, Lin'an District, Tianmushan Nature Reserve (119°27'E, 30°20'N); 26 Apr. 2017; Zhu-Qing He leg. (ECNU). — CHINA • ♂ (542); Zhejiang Prov., Hangzhou City, Lin'an District, Tianmushan Nature Reserve (119°27'E, 30°20'N); 4 Jun. 2017; Zhu-Qing He leg. (ECNU). — CHINA • ♂ (1106); Zhejiang Prov., Hangzhou City, Lin'an District, Qingliangfeng Nature Reserve (118°54'E, 30°06'N); 12 May. 2018; Zhu-Qing He leg. (ECNU). — CHINA • 2♀ (2531, 2532); Zhejiang Prov., Hangzhou City, Lin'an District, Tianmushan Nature Reserve (119°27'E, 30°20'N); 3 Jun. 2019; Di Tian leg. (ECNU).

Diagnosis. Apterous; all glabrous (Fig. 3H); yellow stripes extending from occiput, along eyes to lateral ocel-

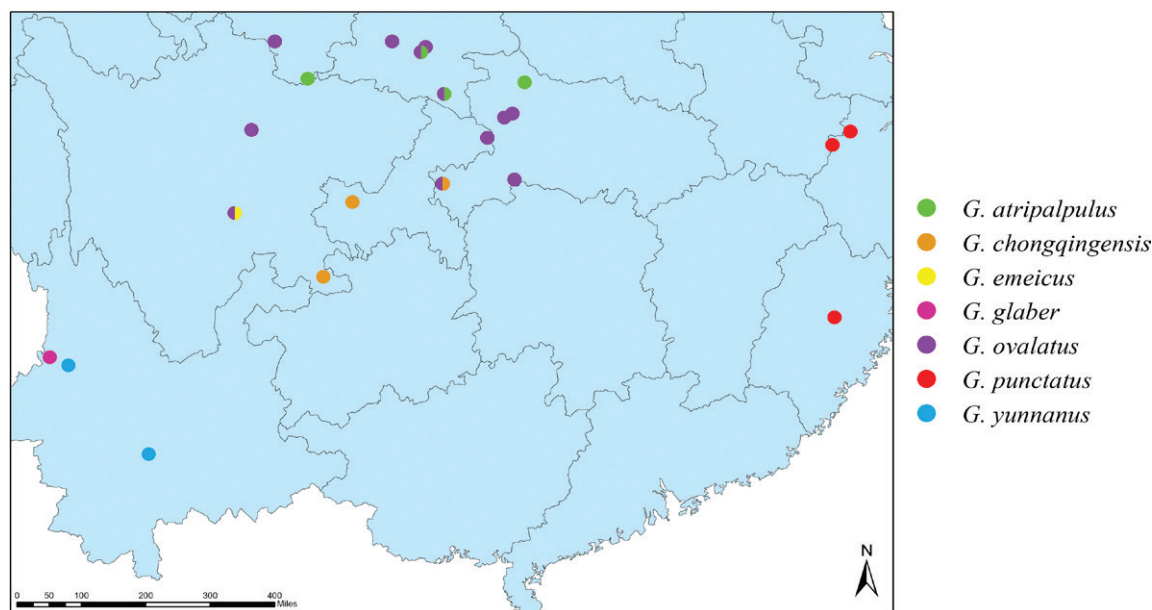


Figure 2. Distribution map of partial *Goniogryllus* based on the new classification including type distribution in China.

li, the yellow stripes divided into two branches from the middle of eyes (Fig. 4K); maxillary palpus black (Fig. 5J); male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes prominent (Fig. 6H).

Measurements. (mm) ♂: BL 12.89–12.91; PL 3.02–3.11; HFL 7.92–8.22. — ♀: BL 13.75–14.29; PL 3.07–3.29; HFL 8.85–8.72; OL 10.18–10.82.

Distribution. China (Fujian, Zhejiang).

Goniogryllus emeicus Wu & Wang, 1992

Goniogryllus emeicus Wu & Wang 1992: 230; Yin and Liu 1995: 191; Chen and Zheng 1996: 291; Zhao and Liu, 2022: 244.

Material examined. CHINA • ♂ (675); Sichuan Prov., Leshan City, Emeishan County, Emeishan (103°21'E, 29°34'N); 31 May. 2017; Wen-Xuan Bi leg. (ECNU). CHINA • ♂ (679); Sichuan Prov., Leshan City, Emeishan County, Emeishan (103°21'E, 29°34'N); 26 May. 2017; Wen-Xuan Bi leg. (ECNU). CHINA • 2♀ (1972, 1982); Sichuan Prov., Leshan City, Emeishan County, Emeishan (103°21'E, 29°34'N); 20 Jun. 2018; Wen-Xuan Bi leg. (ECNU).

Diagnosis. Apterous; all glabrous (Fig. 3I); yellow stripes on head without bifurcation (Fig. 4F); maxillary palpus black with yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint (Fig. 5F); male genitalia: apical part of epiphallus with two divided lobes, the inside of lobes prominent (Fig. 6I).

Measurements. (mm) ♂: BL 10.94–12.37; PL 3.04–3.14; HFL 7.74–8.22. — ♀: BL 13.61–15.59; PL 3.13–3.27; HFL 7.57–8.67; OL 8.97–9.56.

Distribution. China (Sichuan).

Goniogryllus glaber Wu & Wang, 1992

Goniogryllus glaber Wu & Wang 1992: 227; Yin and Liu 1995: 42; Zhao and Liu 2022: 244.

Material examined. CHINA • 2♂ (1974, 1976); Yunnan Prov., Lushui City, Pianma Town (98°37'E 26°00'N); 17 Sep. 2018; Wen-Xuan Bi leg. (ECNU).

Diagnosis. Apterous; all glabrous (Fig. 3J); yellow stripes on the head without bifurcation (Fig. 4G); maxillary palpus black (Fig. 5K); genitalia highly specialized, the apical part of epiphallus scissor-like, ectoparameron slender (Fig. 6A).

Measurements. (mm) ♂: BL 12.13–14.01; PL 2.20–2.37; HFL 6.05–7.08.

Distribution. China (Yunnan).

4. Discussion

The identification of *Goniogryllus* is primarily based on its morphological characteristics (Chopard 1936; Wu and Wang 1992; Chen and Zheng 1995b, 1996). In this study, we examined specimens from various provinces in China including Chongqing, Fujian, Gansu, Hubei, Shaanxi, Sichuan, Yunnan and Zhejiang (Fig. 2). Male genitalia showed that there are only four different types in our study, which indicated a diversity of species lower than current recognized. However, if identification is based on a combination of pubescence, color and wings, they can be classified as eleven different species. Therefore, morphological features in this genus display inconsistent.

The COI gene, also known as DNA barcoding, has proven to be a valuable tool for identifying species, including crickets (Dong et al. 2018; Tan et al. 2021; Li et al. 2021). Additionally, the use of COI gene is encouraged in the publishing of new species (Liu et al. 2018; Tanga et al. 2018; Chen et al. 2019; Li et al. 2021; Liu and He 2022). The single-gene can be used to distinguish different species well. Kim et al. (2022) have suggested that the COI gene is useful for identifying species in the genus *Teleogryllus* Chopard, 1961, but they note that detailed morphological investigations are essential for DNA barcoding before undertaking any molecular study. Hence, in this study, we utilized the COI gene to evaluate the morphological features.

The presence or absence of pubescence on the thorax and abdomen is a classification feature of *G. octospinatus* and *G. pubescens* Wu & Wang, 1992 (Chen and Zheng 1995b). In our results, *G. chongqingensis* (Fig. 3F, G), *G. punctatus* (Fig. 3H), *G. yunnanus* (Fig. 3K), and *G. emeicus* (Fig. 3I) are always glabrous. Male *G. glaber* is also glabrous (Fig. 3J). It is more complex in *G. ovalatus*: pronotum are always pubescent; individuals without wings or with scaly wings are pubescent on mesonotum and metanotum, the abdomen of females is pubescent, while that of males is pubescent only on the first three segments; for individuals with fully developed wings (= *Qingryllus* syn.), they are always glabrous on mesonotum, metanotum and abdomen (Fig. 3A–C). The pubescence of *G. atripalpus* is similar to *G. ovalatus* without wings or with scaly wings, but the pronotum of *G. atripalpus* is glabrous (Fig. 3D, E). Thus, the presence or absence of pubescence on the thorax and abdomen is an important feature (interspecific difference) as in Table 2.

Yellow stripes on the head with or without bifurcation is an important feature mentioned by Wu and Wang (1992), Chen and Zheng (1995b), and their opinion is supported by our results. The yellow stripes of *G. ovalatus* (Fig. 4A–C), *G. chongqingensis* (Fig. 4D, E), *G. emeicus* (Fig. 4F), *G. yunnanus* (Fig. 4H) and *G. glaber* (Fig. 4G) do not bifurcate, while those of *G. atripalpus* (Fig. 4I, J) and *G. punctatus* (Fig. 4K) always bifurcate. Thus, yellow stripes on the head are another specific feature.

The color of the maxillary palpus is another classification feature (Wu and Wang 1992; Chen and Zheng 1995a, 1996; Xie 2005). For example, *G. atripalpus* is similar to *G. bistriatus* Wu & Wang, 1992, but they are different in: the maxillary palpus of *G. atripalpus* is black, while there are yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint of *G. bistriatus* (Wu and Wang 1992). Our results are consistent with theirs: there are yellow stripes on the apex of the 4th joint and the dorsal side of the 5th joint of maxillary palpus of *G. ovalatus* (Fig. 5A–C), *G. chongqingensis* (Fig. 5D, E) and *G. emeicus* (Fig. 5F). There are yellow stripes on the dorsal side of the 5th joint of *G. yunnanus* (Fig. 5G), while the maxillary palpus of *G. atripalpus* (Fig. 5H, I), *G. punctatus* (Fig. 5J) and *G. glaber* (Fig. 5K) are totally black. Thus, the color of the maxillary palpus can be a classification feature.

Most studies describe the male genitalia of most *Goniogryllus* species (Wu and Wang 1992; Chen and Zheng 1995a, 1995b; Xie and Ou 2005; Xie et al. 2006), because the structure is important in modern cricket classification (Randell 1964; He et al. 2009; Gorochov 2015; Tan et al. 2021; Ma et al. 2021). However, the male genitalia of *Goniogryllus* shows minor variations in different species. In our study, *Goniogryllus* are very similar in genitalia except *G. glaber* (Fig. 6A) and *G. yunnanus* (Fig. 6B). There is no process on the inside of the apical lobes of epiphallus of *G. atripalpus* (Fig. 6E, F). On the other side, there are processes on the inside of apical lobes of epiphallus of *G. ovalatus* (Fig. 6C, D), *G. chongqingensis* (Fig. 6G), *G. punctatus* (Fig. 6H), and *G. emeicus* (Fig. 6I).

The color of the pronotum has been mentioned as a classification feature by Wu and Wang (1992), Chen and Zheng (1995a, 1996), and Xie and Zheng (2003). For example, *G. chongqingensis* and *G. octospinatus* are distinguished by the color of the pronotum (Chen and Zheng 1995b). However, our results reveal that there is diversity in the color of pronotum in *G. ovalatus*, *G. chongqingensis*, *G. punctatus*, and *G. atripalpus*. The pronotum of *G. ovalatus* (Fig. 7A–C), *G. chongqingensis* (Fig. 7F, G), *G. punctatus* (Fig. 7H) and *G. atripalpus* (Fig. 7D, E) can be black, or with various yellow spots or stripes on both sides. On the other hand, the color and pattern of the pronotum remain consistent in *G. emeicus* (Fig. 7I), *G. glaber* (Fig. 7J) and *G. yunnanus* (Fig. 7K). Therefore, this feature should be used cautiously in the classification of at least the aforementioned species. Additionally, one distinguishing features between *G. cheni* Xie & Zheng, 2003 and *G. atripalpus* is the presence of yellowish-brown transverse stripes near the anterior margin of the pronotum in *G. cheni*, while they are absent in *G. atripalpus* (Xie and Zheng 2003). Thus, further verification is still required to validate the previous classification based on this morphological feature.

Wu and Wang (1992) mentioned that *G. bomicus* Wu & Wang, 1992 could be distinguished from other species by the color of hind femur. Besides, it is one of the morphological features for distinguishing *G. cheni* from *G. atripalpus* mentioned by Xie and Zheng, 2003 (a yellow longitudinal stripe only at the apex of the hind femur of *G. cheni*, while a yellow longitudinal stripe from one third to the apex of the hind femur of *G. atripalpus*). However, this may be caused by limited samples. In our results, the color of the hind femur is varied. For example, the hind femur of *G. ovalatus* can be black or yellow, or with a yellow longitudinal stripe on the superior margin with varied lengths (Fig. 8A–C). It is in the same situation for *G. atripalpus* (Fig. 8D, E), *G. chongqingensis* (Fig. 8F, G), *G. punctatus* (Fig. 8H), *G. yunnanus* (Fig. 8K), and *G. emeicus* (Fig. 8I). The color of the hind femur of *G. glaber* is yellow with black patterns (Fig. 8J). Thus, we treat the color of the hind femur as one of the intraspecific variations.

Wu and Wang (1992), Chen and Zheng (1995b, 1996), Xie and Zheng (2003), and Xie (2005) point out that the number of dorsal spurs on the hind tibia is a classification



Figure 3. Dorsal view of body. **Aa–Ae** female *G. ovalatus*, **Af–Aj** male *G. ovalatus*; **Ba–Bc** female *Q. striofemorus*, **Bd** male *Q. striofemorus*; **C** female *Q. jiguanshanensis*; **Da** female *G. atripalpus*, **Db** male *G. atripalpus*; **Ea, Eb** female *G. cirilinearis*, **Ec** male *G. cirilinearis*; **F** female *G. chongqingensis*; **Ga** female *G. octospinatus*, **Gb** male *G. octospinatus*; **Ha–Hd** female *G. punctatus*, **He, Hf** male *G. punctatus*; **Ia, Ib** female *G. emeicus*, **Ic–Ie** male *G. emeicus*; **J** male *G. glaber*; **Ka** female *G. yunnanus*, **Kb** male *G. yunnanus*. Scale bar = 2mm.

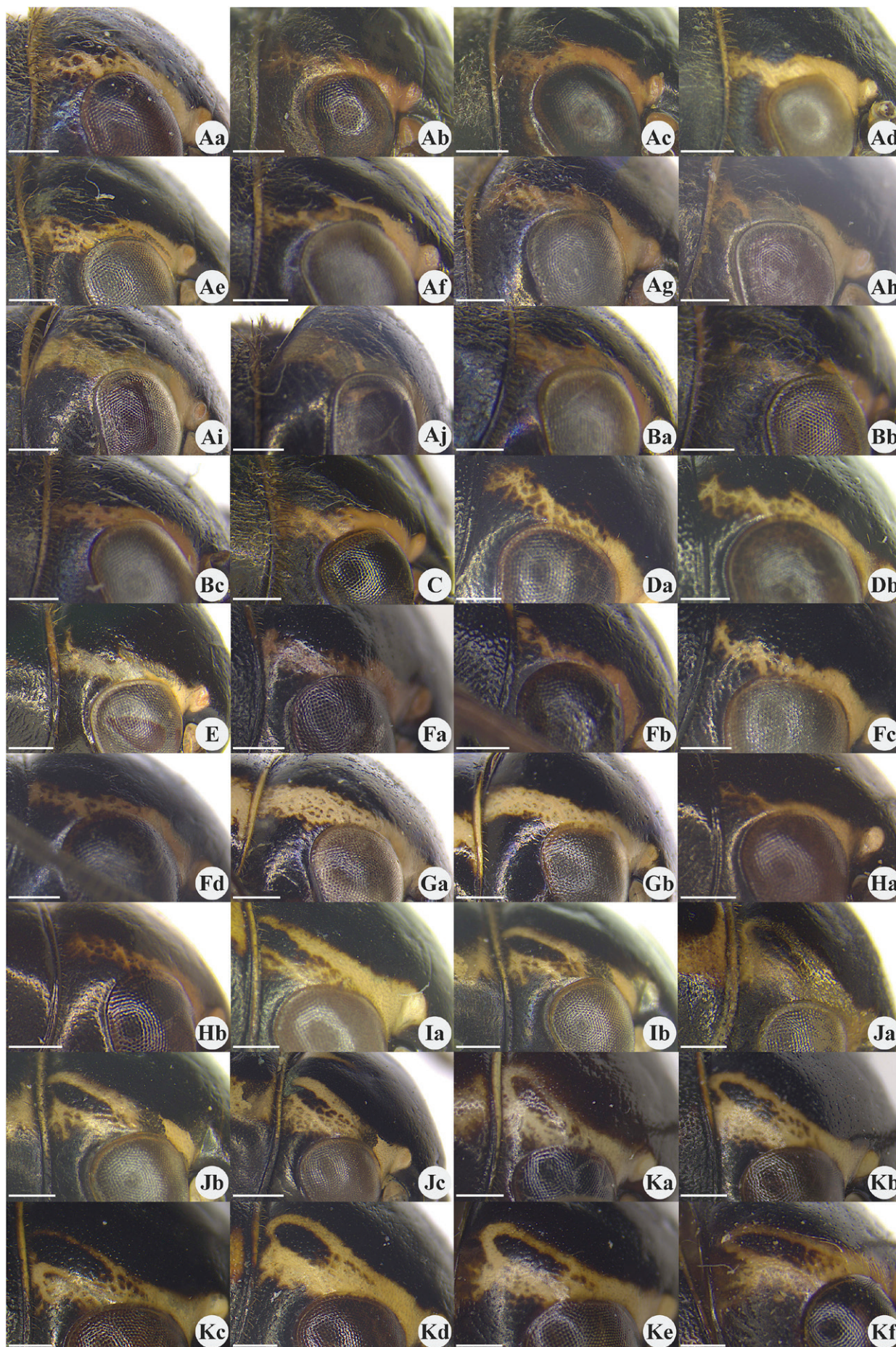


Figure 4. Lateral view of head. **A** *G. ovalatus*; **B** *Q. striofemorus*; **C** *Q. jiguanshanensis*; **D** *G. chongqingensis*; **E** *G. octospinatus*; **F** *G. emeicus*; **G** *G. glaber*; **H** *G. yunnanus*; **I** *G. atripalpulus*; **J** *G. cirilinearis*; **K** *G. punctatus*. Scale bar = 0.5mm.

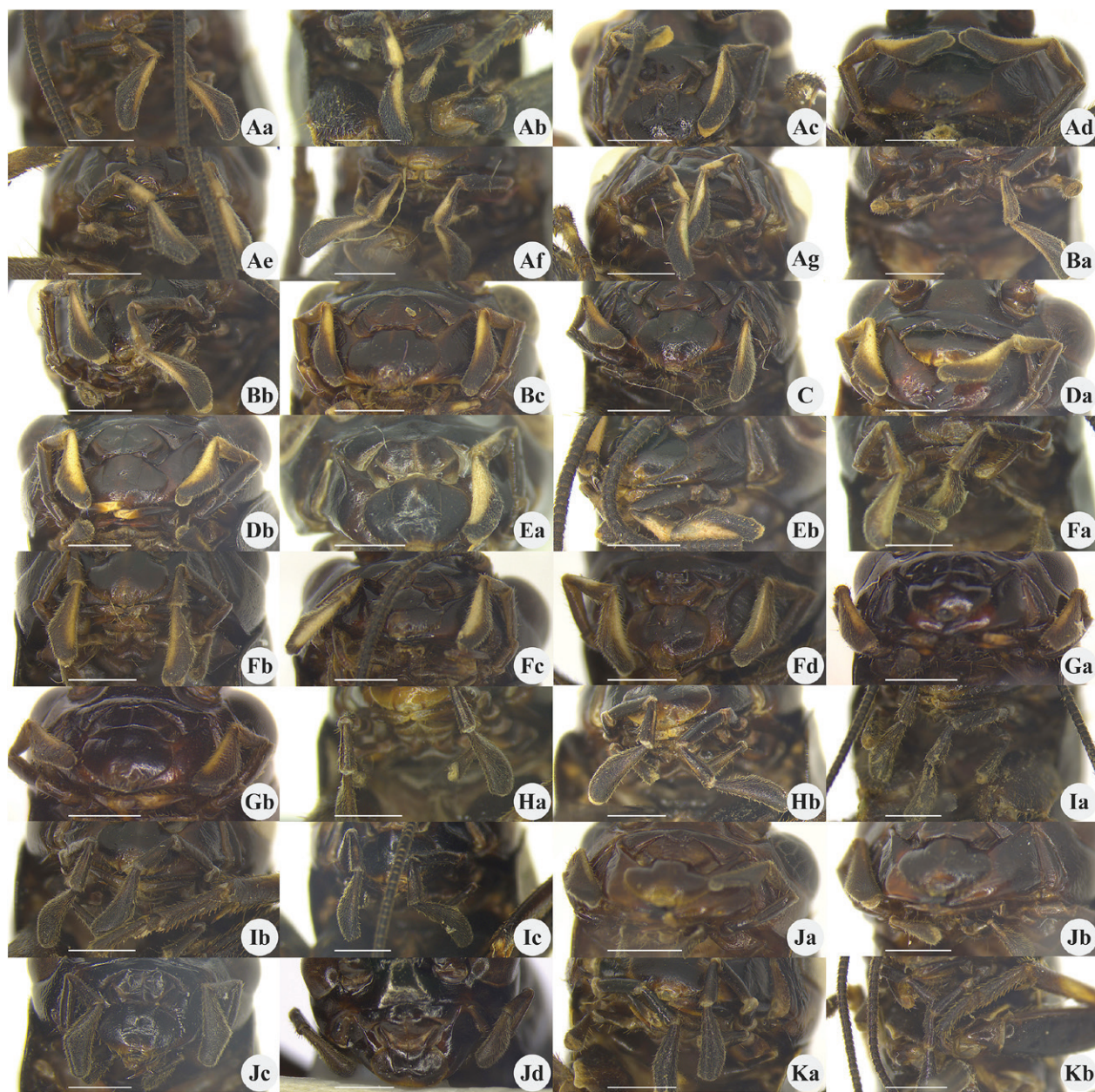


Figure 5. Ventral view of head, showing the color of maxillary palpus. **A** *G. ovalatus*; **B** *Q. striofemorus*; **C** *Q. jiguanshanensis*; **D** *G. chongqingensis*; **E** *G. octospinatus*; **F** *G. emeicus*; **G** *G. yunnanus*; **H** *G. atripalpus*; **I** *G. cirilinearis*; **J** *G. punctatus*; **K** *G. glaber*. Scale bar = 0.5mm.

feature. There are four outer spurs and four inner spurs of *G. octospinatus*, and three outer spurs and four inner spurs of *G. pubescens* (Chen and Zheng 1995b). Our results indicate that the number of dorsal spurs on the hind tibia can be varied in *G. ovalatus*, *G. punctatus*, *G. yunnanus*, and *G. glaber*. *G. ovalatus* possesses three or four outer dorsal spurs and four or five inner ones (Fig. 9A–C). *G. punctatus* possesses three outer ones and four or five inner ones (Fig. 9H). *G. glaber* possesses three or four outer ones and three inner ones (Fig. 9J). *G. yunnanus* possesses three outer ones and three or four inner ones (Fig. 9K). The number of dorsal spurs on hind tibia is stable in *G. atripalpus* (Fig. 9D, E), *G. chongqingensis* (Fig. 9F, G), and *G. emeicus* (Fig. 9I) as 4/4, 4/4, 4/4 (outer/inner), respectively. Thus, the classification de-

pending on the number of dorsal spurs on the hind tibia is questionable in some species. For example, one of the distinguishing features between *G. atripalpus* and *G. sexflorus* Xie & Zheng, 2003 is that the former possesses four outer dorsal spurs and four inner ones, but the latter possesses three outer dorsal spurs and four inner ones (Xie and Zheng 2003).

Our molecular analysis revealed that the specimens in this study can be classified into seven species (six species according to the bPTP method), which supports the classification based on the presence or absence of pubescence on the thorax and abdomen, yellow stripes on the head with or without bifurcation, the color of the maxillary palpus, and the shape of male genitalia. However, in Hubei, Shaanxi, and Sichuan, we encountered some

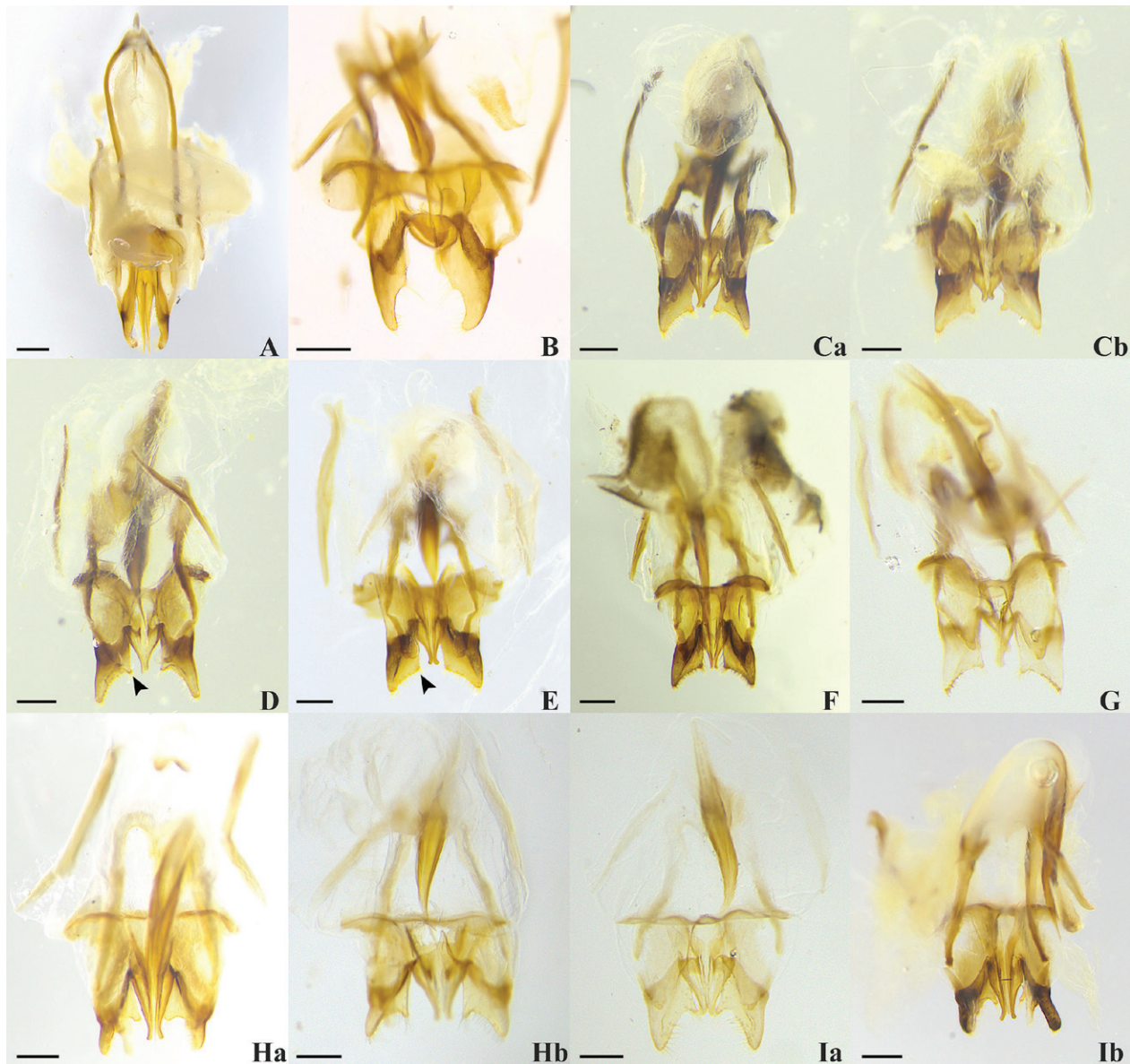


Figure 6. Ventral view of genitalia. **A** *G. glaber*; **B** *G. yunnanus*; **C** *G. ovalatus*; **D** *Q. striofemorus*; **E** *G. atripalpus*; **F** *G. cirlinensis*; **G** *G. octospinatus*; **H** *G. punctatus*; **I** *G. emeicus*. Arrows indicate the inside of the apical lobes of epiphallus. Scale bar = 0.25mm.

“species” that appear different if we rely solely on the color of the hind femur, the color of the pronotum, and the number of dorsal spurs on the hind tibia for identification. When we examined the presence of pubescence on the thorax and abdomen, yellow stripes on the head with or without bifurcation, the color of the maxillary palpus and the shape of male genitalia, these seemingly different “species” showed no discernible variation. Furthermore, our molecular results indicate that they actually belong to the species. Therefore, we consider these features as intraspecific variations.

The presence of specific structures in the male genitalia serves as a mechanism to prevent mating between different species (hybridization), and genital morphology is commonly used for identification purposes in crick-

ets. However, the genitalia of *Goniogryllus* exhibit only minor differences. Nevertheless, molecular analysis and parts of morphological features provide support for classifying them as distinct species. This may be the first example that genitalia cannot be used for identification in crickets as we know. Our hypothesis is that *Goniogryllus* species inhabiting high-altitude regions (Chopard 1969; Wu and Wang 1992; Chen and Zheng 1995a, 1995b, 1996; Xie and Zheng 2003; Xie and Ou 2005; Xie 2005; Xie et al. 2006) face geographical barriers that result in reduced selective pressure on their genitalia. Consequently, male genitalia offer limited assistance in distinguishing between species.

G. yunnanus **comb. nov.** (= *C. yunnanus*) possesses forewings with irregular veins (Fig. 3K), which may lead

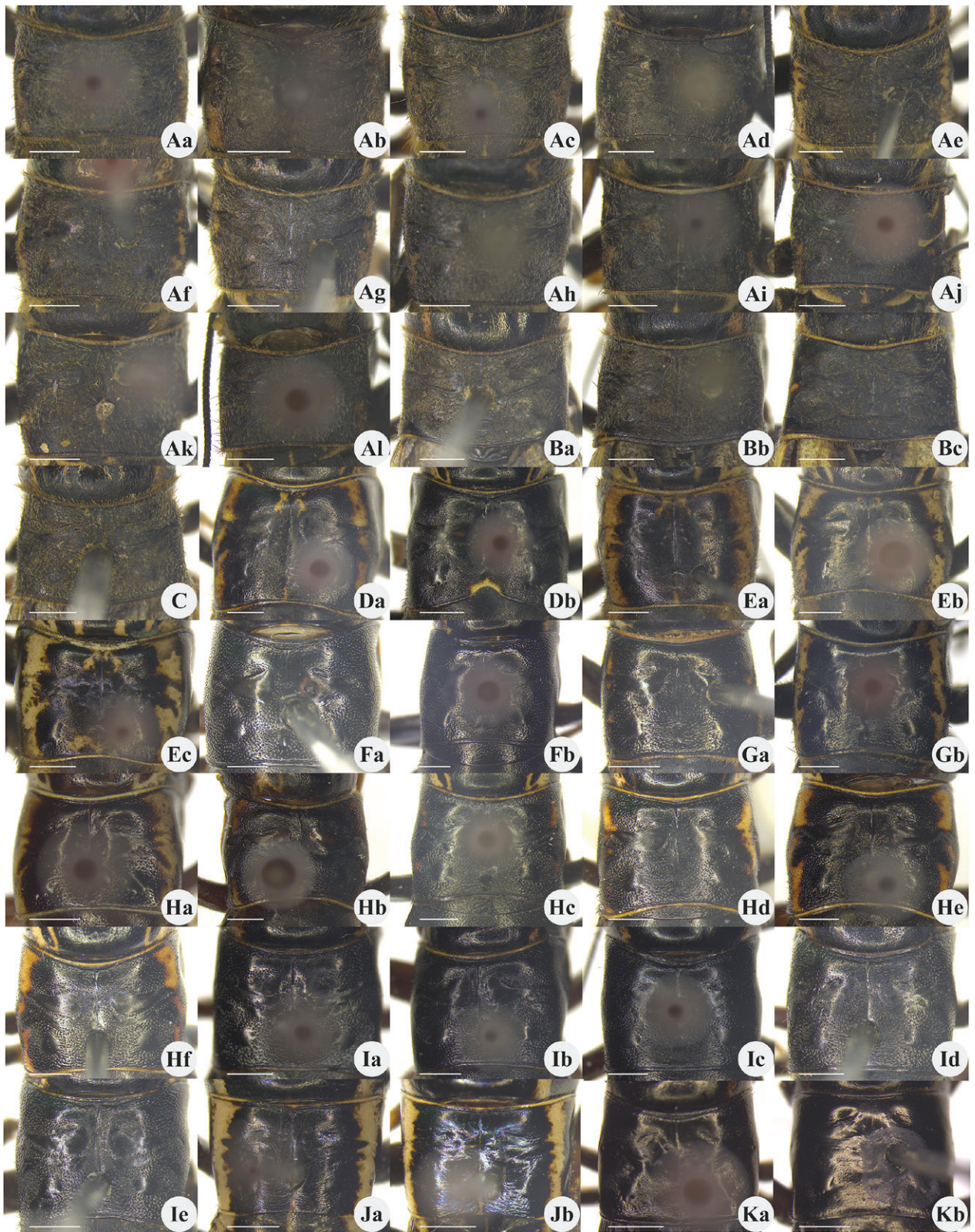


Figure 7. Dorsal view of pronotum. **A** *G. ovalatus*; **B** *Q. striofemorus*; **C** *Q. jiguanshanensis*; **D** *G. atripalpus*; **E** *G. cirilinearis*; **F** *G. chongqingensis*; **G** *G. octospinatus*; **H** *G. punctatus*; **I** *G. emeicus*; **J** *G. glaber*; **K** *G. yunnanus*. Scale bar = 1mm.

to confusion regarding its generic classification. However, based on its genitalia morphology and molecular results, it is evident that this species belongs to the genus *Goniogryllus*. In future study, it would be intriguing to explore the origin and speciation of species in this genus

by incorporating additional genes or conducting phylogenomic analyses.



Figure 8. Dorsal view of hind femur. **A** *G. ovalatus*; **B** *Q. striofemorus*; **C** *Q. jiguanshanensis*; **D** *G. atripalpus*; **E** *G. cirilinearis*; **F** *G. chongqingensis*; **G** *G. octospinatus*; **H** *G. punctatus*; **I** *G. emeicus*; **J** *G. glaber*; **K** *G. yunnanus*. Scale bar = 1mm.

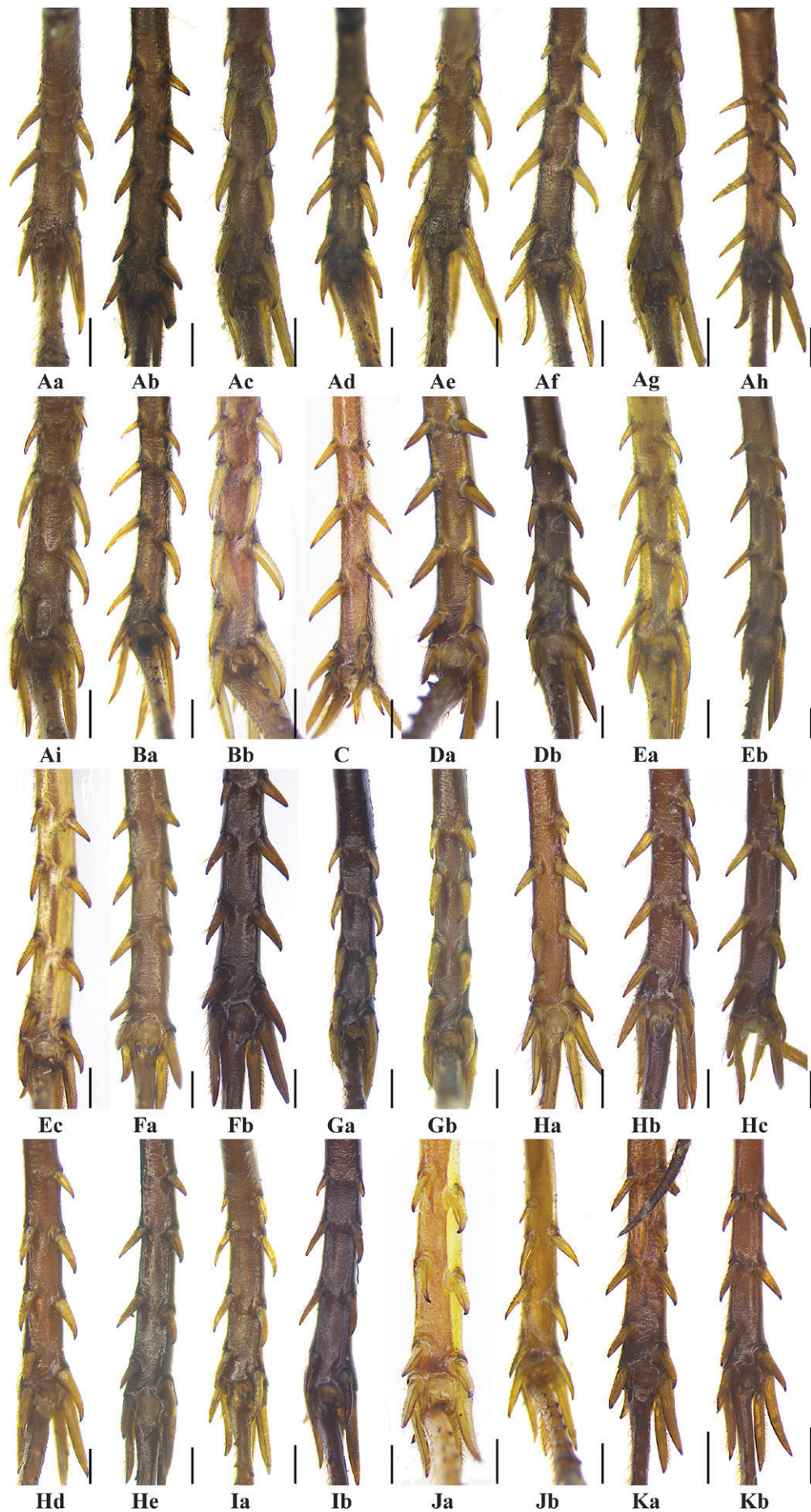


Figure 9. Dorsal view of hind tibiae. **A** *G. ovalatus*; **B** *Q. striofemorus*; **C** *Q. jiguanshanensis*; **D** *G. atripalpus*; **E** *G. cirilinearis*; **F** *G. chongqingensis*; **G** *G. octospinatus*; **H** *G. punctatus*; **I** *G. emeicus*; **J** *G. glaber*; **K** *G. yunnanus*. Scale bar = 0.5mm.

5. Conclusions

In conclusion, some morphological features, such as the presence or absence of pubescence on the thorax and abdomen, yellow stripes on the head with or without bifurcation, the color of the maxillary palpus and the shape of male genitalia are interspecific differences, and these can be used as classification features. However, the color of the hind femur and pronotum, and the number of dorsal spurs on hind tibia show intraspecific variations in some species. Therefore, the classification based solely on these morphological features requires verification, particularly for the aforementioned species with only intraspecific variations when published. We recommend that future studies consider utilizing these interspecific differences, increase the sample size, or incorporate molecular data for more robust classification.

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Supplementary Material 1

Table S1

Authors: Guo YJ, An SQ, Fang ZG, Wei SF, Shen ZH, Chen ZY, He ZQ (2024)

Data type: .docx

Explanation notes: Description of the Collecting information and COI GenBank accession number of Gryllini.

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