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Species delimitation and taxonomic revision of *Oxyopes* (Araneae: Oxyopidae) of Taiwan, with description of two new species

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Abstract

This study revised the spider genus *Oxyopes* Latreille, 1804 in Taiwan and delineated the species boundaries based on morphological and molecular characters. A total of seven *Oxyopes* spiders were recognized, including two newly described species, *O. hasta* **sp. nov.** and *O. taiwanensis* **sp. nov.** *Oxyopes fujianicus* Song & Zhu 1993 from Yilan County, Nantou County, and Kaohsuing City, and *O. striagatus* Song 1999 from New Taipei City, Taichung City, Nantou County, and Kaohsiung City were recorded for the first time in Taiwan. An identification key and a distributional map of Taiwanese *Oxyopes* species were provided. Partial *COI* sequences were obtained for molecular phylogenetic and species delimitation analyses. Maximum likelihood and Bayesian phylogenies, and DNA barcoding gap analysis supported morphologically defined species. However, molecular species delimitation based on Automatic Barcode Gap Discovery (ABGD), P_{ID} (Liberal), and generalized mixed Yule coalescent (GMYC) were incongruent in species assignment. The results showed that the interspecific genetic divergence between *O. sertatus* and *O. taiwanensis* was relatively low (1.28 ± 0.43%), and the intraspecific genetic divergence of *O. striagatus* was relatively high (1.69 ± 0.35%). Ecological data, additional samples and genetic loci are required to further examine the level of reproductive isolation and patterns of population genetic structure in Taiwanese *Oxyopes*.

Key words: Endemism, island biodiversity, lynx spider, phylogeny, species delimitation, taxonomy

Introduction

The family Oxyopidae (Lynx spiders) currently has 438 species and nine genera, which are distributed worldwide (World Spider Catalog 2020). They can be distinguished from other spider families by their hexagonal eye arrangement and legs with conspicuous and erect black spines (Brady 1964; Brady & Santos 2005). Lynx spiders are cursorial hunters in the foliage of various habitats such as grasslands, forest canopies, and farmlands. Because the oxyopids are dominant and generalist predators in many agroecosystems, they have attracted attention for their potential role in the biological control of crop pests (Nyffeler *et al.* 1987, 1992; Maloney *et al.* 2003; Michalko *et al.* 2019). For example, Basnet & Mukhopadhyay (2014) suggested that *Oxyopes javanus* Thorell can be an effective natural enemy of the mosquito bug *Helopeltis theivora* Waterhouse (Hemiptera, Miridae), a major tea pest in the Himalayas of NE India. Shivakumar & Kumar (2010) suggested *O. shweta* Tikader is an effective natural enemy in regulating the population of cotton leafworm larvae, *Spodoptera litura* (Fabricius) (Lepidoptera, Noctuidae). However, the taxonomy and species diversity of many regional lynx spider fauna worldwide are still little known (Tang and Li 2012; Mukhtar 2017), which hinders their identification and application as an effective biological control agent in agroecosystems.

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Oxyopes Latreille, 1804, is the largest genus of lynx spiders and is composed of 286 described species (World Spider Catalog 2020). *Oxyopes* can be distinguished from other lynx spider genera by the following diagnostic characters: PME row subequal to ALE row, distance between PME subequal to distance between PME and PLE, and leg IV distinctly longer than leg III (Brady 1964; Brady & Santos 2005). For *Oxyopes* of Taiwan, Saito (1933) first reported *O. sertatus* based on five female and two immature male specimens collected from Nitsugetsutan (Nantou County) and Urai (New Taipei City), in central and northern Taiwan, respectively. Later, Chu & Okuma (1970) reported *O. macilentus* based on four female and one juvenile specimens from Wu-feng (Taichung City), Mei-chi and Chun-yuan (Nantou County), in central Taiwan. These two studies provided little morphological description for the confirmation of species identification. Lo & Lin (2016) recently reported one new record of *O. sushilae* Tikader in Taiwan and provided a detailed morphological redescription. Until now, only three *Oxyopes* species are known from Taiwan. However, our own field studies suggested that the *Oxyopes* species diversity remain underestimated in Taiwan.

Previous taxonomic studies on *Oxyopes* spiders were primarily based on the morphology of the genital organs, which is known to be a useful character for species identification. For example, the shape and location of the retrolateral tibial apophysis, embolus, conductor, and median apophysis of male specimens, and the shape of the epigyne and spermatheca, and orientation of the copulatory duct for female specimens are all crucial traits for identifying *Oxyopes* species (Tang and Li 2012; Baehr *et al*. 2017; Santos 2017). However, studies on other spider families suggest that morphological characters can sometimes be ambiguous among closely related or cryptic species, which can lead to inaccurate species delimitation (Duncan *et al.* 2010; Satler *et al*. 2013). DNA barcoding based on the mitochondrial cytochrome oxidase subunit I (*COI*) gene (Hebert *et al*. 2003) provides an alternative approach for identifying and delimiting spider species (Barrett & Hebert 2005; Hamilton *et al*. 2011; Welton *et al*. 2014; Agnarsson *et al*. 2016; Hsiao *et al*. 2016; Jin *et al*. 2018). DNA barcoding using the *COI* gene was highly effective in discriminating the spider species of Canada (Barrett & Hebert 2005; Robinson *et al*. 2009; Blagoev *et al*. 2016), and is now routinely used in the species delimitation and identification of spiders in regional faunas (Xu *et al*. 2015; Cao *et al*. 2016; Nadolny *et al*. 2016; Hormiga 2017).

In this study, we revise the taxonomy and investigate the species boundaries of *Oxyopes* in Taiwan based on morphological characters and mitochondrial *COI* sequences. We use four species delimitation methods to test the species boundaries of Taiwanese *Oxyopes* and to evaluate the level of congruence among methods.

Materials and methods

Specimen collecting, preparation and morphological study

The spider specimens, including *Oxyopes* and outgroup *Peucetia*, were collected by hand or sweeping net in 43 field sites throughout Taiwan from 2013 to 2018 (Fig. 1). The specimens were preserved in 75% ethanol immediately after collecting, and then sorted and examined using a stereomicroscope (Leica MZ125; Wetzlar, Germany). The selected specimens were dissected to examine the male palpal organ and the female epigyne. To dissect the female genital organs, the epigyne and inner genital structures were cleaned in a heated 10% KOH solution. The majority of the setae on the cymbium of the male palp were removed using tweezers and insect pins for the observation of fine structures; thus they are absent in the illustrations. The photos of the specimens were taken with a digital camera (Nikon D850; Tokyo, Japan) mounted on a stereomicroscope. Series of photos with various focal depths for a given specimen was stacked automatically using Helicon Focus version 6 (Helicon Soft Ltd, Kharkiv, Ukraine). A scale bar with reference to the size of the specimen was inserted on the digital image using ImageJ version 1.52k (National Institutes of Health, Bethesda, Maryland, USA) and Photoshop version 19.1.2 (Adobe Systems Corporation, San Jose, CA, USA). Morphological structures were drawn with the aid of a drawing tube attached to the stereomicroscope. Measurements of all morphological structures were obtained using a micrometer mounted on the eyepiece of the stereomicroscope. All measurements are given in millimeters. The measurements of the pedipalp and legs are given as the total length (pedipalp: femur, patella, tibia, and tarsus lengths; leg: femur, patella, tibia, metatarsus, and tarsus lengths). All voucher specimens are deposited in the Endemic Species Research Institute, Taiwan (**TESRI**).

The abbreviations followed Crews & Harvey (2011) and Zhang & Zhang (2018): **AER**, anterior eye row; **ALE**, anterior lateral eye; **AME**, anterior median eye; **AME-I**, interdistance between anterior median eyes; **AML-I**,

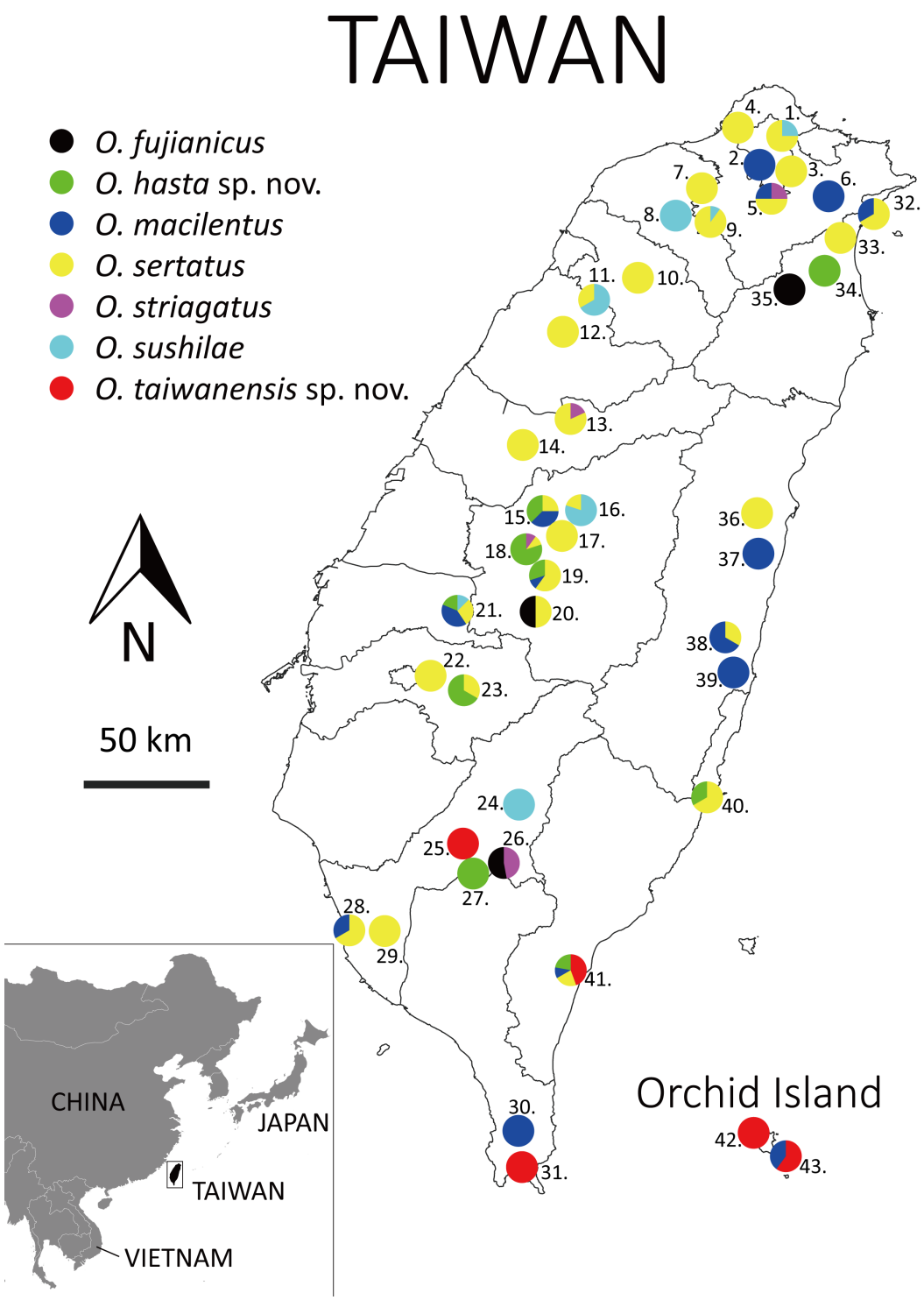

FIGURE 1. Collection sites of *Oxyopes* species in this Taiwan. 1, Pamier Park; 2. National Taiwan University; 3, Taipei Zoo; 4, Niugangleng Hiking Trail; 5. Changxing Road; 6. Pinglin Tea Garden; 7, Bade Pond Ecology Park; 8, Datieliao Old Trail; 9, Sanmin; 10, Daqidong Trail; 11, Shitoushan; 12, Mingfong Historical Trail; 13, Wushikeng Experimental Station; 14, Dakeng; 15, Jiufenershan; 16, Taomikeng; 17, Lianhuachi; 18, Zhongliao; 19, Jiji; 20, Fonghuang Tea Garden & Bird and Ecological Park; 21, Qipan village; 22, Lantan Trail; 23, Chukou Nature Center; 24, Shishan forest road; 25, Shihba Luohanshan; 26, Duona Forest Road; 27, Maolin Ecological Park; 28, Shoushan National Nature Park; 29, Niaosong Wetland Park; 30, Laofoshan; 31, Kenting; 32, Shikong Historical Trail; 33, Paoma Historical Trail; 34, Yuanshan; 35, Jiuliaoxi Ecological Park; 36, Tongmen Bridge; 37, Baibaoxi; 38, Daduhua; 39, Qimei village; 40, Juzishan; 41, Jinlun Forest Road & Duoliang Village; 42, Orchid Island (Xiaotianchi); 43, Orchid Island (Hongtou & Dongqing).

interdistance between anterior median and lateral eyes; **CD**: copulatory duct; **C**: conductor; **CO**: copulatory opening; **Em**: embolus; **FD**: fertilization duct; **MA,** median apophysis; **MOA**, median ocular area; **MOA-AW**, anterior width of median ocular area; **MOA-L**, length of median ocular area; **MOA-PW**, posterior width of median ocular area; **PER**, posterior eye row; **PLE**, posterior lateral eye; **PME**, posterior median eye; **PME-I**, interdistance between posterior median eyes; **PML-I**, interdistance between posterior median and lateral eyes; **dRTA**: dorsal retrolateral tibial apophysis; **vRTA**, ventral retrolateral tibial apophysis; **S**, spermatheca; **SE**, sclerotized edge.

The abbreviations for institutions where specimens were deposited in: **IZCAS**, Institute of Zoology, Chinese Academy of Sciences; **TESRI**, Taiwan Endemic Species Research Institute; **ZMH**, Zoologisches Museum Hamburg; **ZSI**, Zoological Survey of India.

DNA extraction and sequencing

The tissue from one or two legs of the collected specimens were preserved in 95% ethanol until DNA extraction. Genomic DNA was extracted from leg tissue using Puregen Core Kit A (Qiagen, Valencia, CA, USA). The partial cytochrome c oxidase subunit I gene (*COI*) was amplified using the primer pairs LCO 1490 and HCO 2198 (Folmer *et al*. 1994). The polymerase chain reaction (PCR) protocol was as follows: initial denaturation at 95 °C for 5 min; 35 cycles of denaturation at 95 °C for 30 sec, annealing at 45 °C for 30 sec, and elongation at 72 °C for 30 sec; and a final extension at 72 °C for 5 min. The 25-μL PCR reactions included 9.5 μL of double-distilled H_2O, 1 μL of each forward and reverse primer (10 μM), 1 μL of DNA template, and 12.5 μL *Taq* DNA Polymerase 2× Master Mix RED (with 1.5 mM $MgCl_2$ final concentration; Ampliqon, Herlev, Denmark). The PCR products were visualized through agarose gel electrophoresis (1% agarose) and products were sequenced by Genomics BioSci & Tech. Co., Ltd. (New Taipei City, Taiwan) using an ABI 3730xl DNA Analyzer.

Phylogenetic inference

The DNA sequences were trimmed and edited using SeqMan in DNASTAR (Swindell & Plasterer 1997), and then aligned with ClustalW in BioEdit v.7.0.5.3 (Hall 1999). DnaSP 6.12 (Rozas *et al*. 2017) was used to identify haplotypes and polymorphic sites. The TIM+G model was selected as the best-fit nucleotide substitution model for Bayesian inference (BI) analysis based on jModelTest v.2.1.7 (Darriba *et al*. 2012) using Bayesian information criterion. Bayesian phylogenetic analyses were conducted in MrBayes v.3.2 (Ronquist *et al*. 2012) using Markov chain Monte Carlo (MCMC) searches for two million generations with sampling every 1000 generations. Average standard deviation of split frequencies was never greater than 0.01 after 153,0000 generations and oscillated between 0.008 and 0.009 after 172,5000 generations. Convergence of the MCMC runs was confirmed using the effective sample sizes (ESS > 200) of the model parameters in Tracer v.1.7.1 (Drummond & Rambaut 2007). Bayesian posterior probability was calculated from a 50% majority-rule tree after discarding a burn-in of 10% of the trees. Maximum likelihood (ML) analysis was carried out in RAxML (Stamatakis 2006). Because the program only supports GTR models, we chose GTR+G, which is the most similar to the model inferred for the BI analysis. All the other parameters were set to the default values and the branch support for the nodes was estimated by 1000 standard bootstrap replicates.

Species delimitation

Seven potential *Oxyopes* species were recognized based on morphology and the topology of the BI and ML phylogenetic trees, then we tested these taxonomic hypotheses using DNA barcoding gap analysis (Hebert *et al.* 2004; Meyer & Paulay 2005). We calculated the mean interspecific and intraspecific genetic distances (Kimura-two-parameter [K2P]) using MEGA7 (Kumar *et al*. 2016) and the pairwise interspecific and intraspecific genetic distances using the ape (Paradis & Schliep 2018) and spider (Brown *et al*. 2012) R packages (R Core Team 2019), then examined the overlap between the interspecific and intraspecific genetic distances.

We also tested species limits using ABGD (Puillandre *et al*. 2012), a method based on the concept of barcoding gap, in which the genetic distance within the same species is smaller than that among different species. The ABGD analysis calculates all pairwise genetic distances and ranks them by increasing values. The local slope is then computed for a given window size, and the program reports the local distance as the barcoding gap by detecting the peaks of slope values. Once the barcoding gap was computed, the dataset is partitioned into groups and then recursively partitioned into finer groups using the same method until no further gap could be detected. We carried out ABGD analysis using a command-line version with K2P (Kimura 1980) genetic distances and default parameters

values (prior minimum intraspecific divergence [Pmin] = 0.001; prior maximum intraspecific divergence [Pmax] = 0.1; proxy for the minimum relative gap width [X] = 1.5).

P_{ID} (Liberal), the mean probability (with the 95% confidence interval) of making a correct identification under relaxed cladistic criteria (Masters *et al*. 2011), was calculated using the Species delimitation plug-in (SDP) in Geneious Prime v.2019.2.1 (http://www.geneious.com; Masters *et al*. 2011). SDP allows users to assess alternative putative species hypotheses in the phylogenetic tree, rather than providing definitive support for species delimitation. Because the barcoding gap analysis revealed that the interspecific divergence between *O. sertatus* and *O. taiwanensis* was smaller than 2% (see Results), we examined an alternative hypothesis in which these two lineages are a single species in SDP. P_{ID} (Liberal) is predicted from the ratio of Intra Dist (the average pairwise distance among members of the focal species) to Inter Dist (the average pairwise distance between members of focal species and members of the closest species), which is derived from the regression model using the simulation method of Ross *et al*. (2008). The liberal criterion requires the query sequence to fall within or be a sister to a monophyletic group. SDP also computes Rosenberg's P_{AB} statistic, which is the probability that a putative species will be reciprocally monophyletic with respect to a sister clade containing other taxa under the null model of random coalescence (Rosenberg 2007). The BI tree was imported as a guide tree in the analysis.

The GMYC (Pons *et al*. 2006) delineates species boundaries by detecting a transition point on an ultrametric phylogenetic tree where the branching pattern switches from interspecific (speciation) to intraspecific (coalescent) processes. We conducted GMYC analyses using the splits package in R (Ezard *et al.* 2009). The ultrametric phylogenetic tree was obtained using BEAST 2 (Drummond *et al*. 2007; Bouckaert *et al*. 2014) under a strict molecular clock model with either Yule speciation or a coalescent model, with the default parameter settings. The analyses were run for two million generations with sampling every 1000 generations. We assessed the convergence of MCMC runs using the effective sample sizes (ESS > 200) of the model parameters in Tracer v.1.7.1 (Rambaut *et al*. 2018). The maximum clade credibility tree was constructed after discarding 10% of the sampled trees as burn-in in TreeAnnotator v.2.4.5 (Rambaut & Drummond 2016).

Results

Taxonomic hypothesis

Seven morphologically distinct *Oxyopes* species were recognized based on diagnostic characters of the genital organs and the topology of the phylogenetic trees (Fig. 2). Two new species, *O. hasta* **sp. nov.** and *O. taiwanensis* **sp. nov.** were discovered and described below. Morphological characters of the other five Taiwanese *Oxyopes* species, including the palp, epigyne, and habitus are also described in the Taxonomy section. While most species can be distinguished from each other by the male palpal organs, such as the shape of the retrolateral tibial apophysis (Figs 3–10), the female epigyne and internal genitalia are similar among these species (for example, *O. sertatus* and *O. taiwanensis*; Figs 7, 9).

Genetic variation and phylogenies

COI sequences of 660 base pairs (bp) were obtained without gap from 45 individuals of *Oxyopes* spiders and the outgroup. The *COI* dataset had 115 variable sites, 111 parsimony informative sites, and 21 unique haplotypes (Appendix S1, Dryad Digital Repository: https://doi.org/10.5061/dryad.m905qfv05). The haplotype diversity of *O. fujianicus* Song & Zhu, 1993 (N = 4) and *O. sushilae* (N = 2) were low (0), whereas *O. macilentus* L. Koch, 1878 (N = 9) had the highest haplotype diversity (0.89) among the seven species (Table 1). The *COI* phylogenies reconstructed using BI and ML methods had identical topologies (Fig. 2). The putative species were all strongly supported as monophyletic lineages (posterior probability > 0.95; bootstrap value > 70), with the exception of *O. taiwanensis* clade, which had a posterior probability of 0.87. All mean interspecific divergences between putative species were greater than 6% (Table 1 and Appendix S2, Dryad Digital Repository: https://doi.org/10.5061/dryad.m905qfv05) except for one species pair, *O. sertatus* L. Koch, 1878 and *O. taiwanensis* (1.28%), which was smaller than the intraspecific divergence of *O. striagatus* Song, 1991, and much smaller than those of spider species in previous studies (Barrett & Heberts 2005; Čandek & Kuntner 2015; Blagoev *et al*. 2016). The mean intraspecific divergence was under 2% for all putative species (Table 1 and Appendix S2, Dryad Digital Repository: https://doi.org/10.5061/dryad.m905qfv05) and the highest was found in *O. striagatus* (1.69%).

TABLE 1. Mean intraspecific and closest interspecific genetic distances of Taiwanese *Oxyopes* species based on the K2P model.

Species	N	Number of haplotypes	Haplotype diversity	Intraspecific distance (%)	Closest interspecific distance (%)	Closest species
O. fujianicus	4	1	0	0	7.08 ± 1.13	*O. sushilae*
O. hasta	15	5	0.78	0.38 ± 0.14	6.38 ± 1.02	*O. taiwanensis*
O. macilentus	9	6	0.89	0.29 ± 0.11	7.04 ± 1.15	*O. sushilae*
O. sertatus	3	2	0.67	0.20 ± 0.14	1.28 ± 0.43	*O. taiwanensis*
O. striagatus	6	4	0.80	1.69 ± 0.35	6.38 ± 0.92	*O. sushilae*
O. sushilae	2	1	0	0	6.38 ± 0.92	*O. striagatus*
O. taiwanensis	4	2	0.50	0.08 ± 0.07	1.28 ± 0.43	*O. sertatus*

Molecular species delimitation

Barcoding gap analysis supported the seven potential *Oxyopes* species recognized based on morphological characters, with the mean interspecific divergence of the closest species for all putative species being at least 3.78 times greater than the mean intraspecific divergence (Table 1). ABGD analyses revealed six species in both initial and recursive partitions with prior intraspecific divergence values (P) of 0.0215 and 0.0359 (Appendix S3, Dryad Digital Repository: https://doi.org/10.5061/dryad.m905qfv05), respectively. In contrast to species boundaries defined by the morphological characters and phylogenetic tree topologies, *O. sertatus* was not distinguished from *O. taiwanensis* by ABGD (Fig. 2). The result of SDP also supported six species (Fig. 2), with the P_{ID} (Liberal) value of *O. sertatus* + *O. taiwanensis* lineages (0.96) being higher than those of *O. sertatus* (0.86) and *O. taiwanensis* (0.95) (Appendix S4, Dryad Digital Repository: https://doi.org/10.5061/dryad.m905qfv05). Rosenberg's P_{AB} value of *O. sertatus* + *O. taiwanensis* lineages (< 0.001) was smaller than that of *O. sertatus* and *O. taiwanensis* (0.01) lineages. GMYC analyses estimated eight or nine species depending on different models (Figure 2). *Oxyopes sertatus* and *O. taiwanensis* were distinguished based on a prior coalescent (population) model, but not under the Yule (speciation) model. In contrast to the other delimitation methods, both GMYC models split *O. striagatus* into three species.

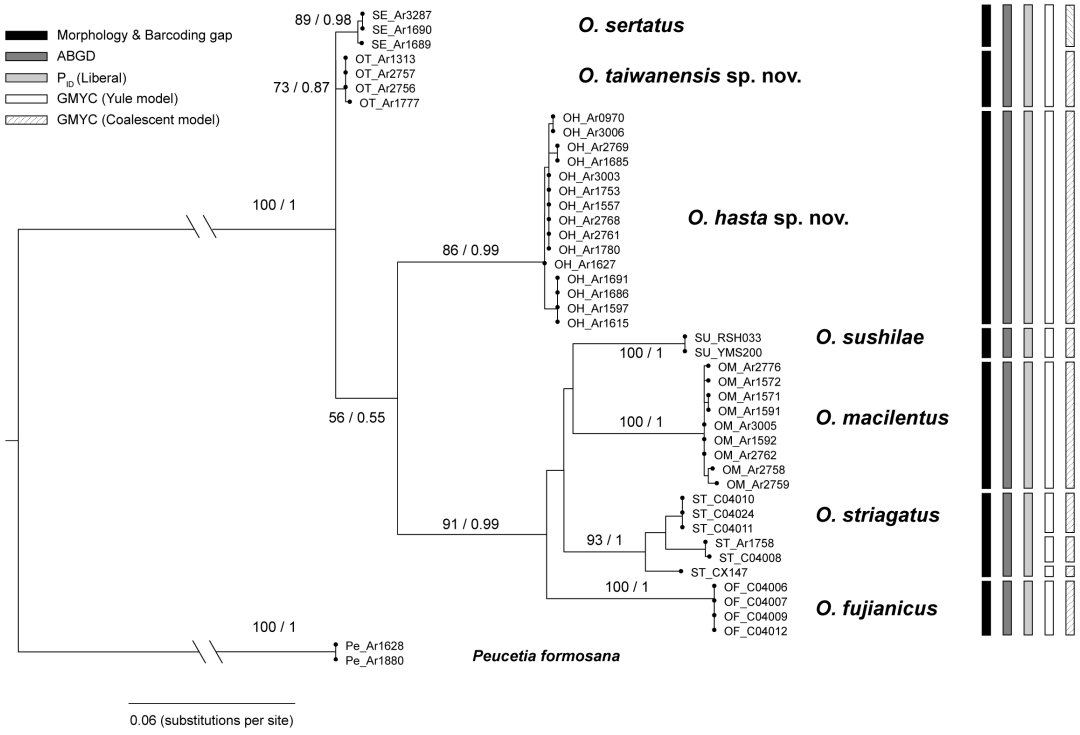

FIGURE 2. Maximum likelihood (ML) phylogenetic tree and species delimitation of *Oxyopes* species in Taiwan based on the *COI* gene dataset. Numbers above branches are bootstrap values and Bayesian posterior probabilities. Species were assigned based on morphological characters.

Discussion

We identified seven *Oxyopes* species in Taiwan based on morphological characters, including two new species, *O. hasta* **sp. nov.** and *O. taiwanensis* **sp. nov.**, and two species newly recorded from the country, *O. fujianicus* and *O. striagatus*. The morphologically defined species were supported by *COI* phylogenies. All seven Taiwanese *Oxyopes* species were monophyletic, indicating that they are valid phylogenetic species (Fig. 2). The nearest interspecific distances were larger than the intraspecific distances for the seven *Oxyopes* species, suggesting that they form distinct genetic clusters and a genetic barcoding gap exists between them. However, species delimitation methods based on *COI* sequences did not fully corroborate those recognized by morphological characters (Fig. 2). One of the major differences was the number of species in the *O. sertatus* + *O. taiwanensis* lineage. The GMYC with coalescent (population) model was consistent with the morphological characters in supporting two species. The ABGD, P_{ID} (Liberal), and GMYC with Yule (speciation) model, however, supported *O. sertatus* + *O. taiwanensis* as a single species. Several studies suggested that distinct morphological divergence with weak genetic differentiation can be accelerated under strong selection pressure, phenotypic plasticity, a slower rate of molecular evolution, or an insufficient time to accumulate genetic differences in recently diverged populations or species (Vitt *et al.* 1997; Nice & Shapiro 1999; Hu *et al.* 2019). A similar case of inconsistency between morphological and genetic species was reported in two *Paiwana* (Pholcidae) spiders, *P. pingtung* and *P. chengpoi* (Huber & Dimitrov, 2014) in Taiwan. These species differ conspicuously in their body proportions, color patterns, and microhabitats, but their *COI* sequences are almost indistinguishable (*p*-distance between the closed population was 0.0–0.8%) (Huber & Dimitrov 2014). This result suggested that a recent microhabitat shift with insufficient time to accumulate genetic difference would not have allowed the discovery of these two spider species based only on genetic divergence. Hu *et al*. (2019) also reported another case in which the species boundary between two species of the toad-headed lizard *Phrynocephalus* (Agamidae) was distinguishable with morphological rather than genetic traits. They suggested that the morphological divergence with weak genetic differentiation could have resulted from a high level of gene flow and introgressive hybridization between species that live in different environments. The examples above suggest potential explanations for the low pairwise interspecific divergences between *O. sertatus* and *O. taiwanensis* (1.23%–1.38%), despite the strong morphological divergence. Although the morphological difference between them may represent population subdivision rather than separate species, we chose to keep these lineages as separate species based on the following reasons. (1) The morphological difference of genitalia characters in both sexes between these two species were notable and stable, with no intermediate forms discovered until now. (2) The interspecific divergence between these two species is at least 6 times greater than that of the intraspecific divergence (Table 1), which suggests the existence of a barcoding gap. Furthermore, (3) there is no evidence to indicate that they occur together in the same micro-habitat even though these two species have an overlapping distribution in southeastern Taiwan. Further studies on the ecological and behavioral characteristics associated with reproductive isolation, such as courtship display, would be necessary to understand the mechanism leading to morphological differentiation with low genetic divergence between *O. sertatus* and *O. taiwanensis*.

Another difference in the results of species delimitation methods was the number of species within the *O. striagatus* lineage. GMYC delimitation based on both Yule and coalescent models split the *O. striagatus* lineage into three species, but it was estimated to be one species in the morphological and other delimitation methods (Fig. 2). GMYC is known to overestimate the number of species, and its performance can be affected by several factors, such as the accuracy of phylogeny, completeness of sampling, and level of population structure (Lohse 2009; Papadopoulou *et al*. 2009; Esselstyn *et al.* 2012; Reid & Carstens 2012; Prévot *et al*. 2013; Talavera *et al*. 2013; Hamilton *et al*. 2014; Xu *et al*. 2015). The multispecies coalescent approach of GMYC possibly detects genetic structure rather than species, and it could misidentify population structure as putative species (Sukumaran & Knowles 2017). Our results showed that the intraspecific genetic distance of *O. striagatus* is relatively higher (1.69% ± 0.35%) than those of other Taiwanese *Oxyopes* species (0.0%–0.38%, Table 1), suggesting the existence of substantial genetic divergence between central (Zhongliao) and southern (Duona Forest Road) populations, which may have caused GMYC to overestimate the number of species in the *O. striagatus* lineage. Based on the morphology, barcoding gap, ABGD and P_{ID} (Liberal), we recognize the *O. striagatus* lineage as a single species. Since the geographic distribution of *O. striagatus* in Taiwan is still unclear, additional sampling is necessary to further examine its genetic structure.

The short divergence times and limited morphological divergence of island organisms may obscure species boundaries, which leads to the underestimation of endemic biodiversity on islands (Bickford *et al.* 2007). Integra-

tive taxonomic studies using morphological, genetic, and ecological data were important and useful to discriminate cryptic species. Among endemic Taiwanese species, for example, Chen *et al*. (2017) used an integrated species delimitation approach combining morphological, molecular, and ecological traits to recognize two cryptic species of an endangered weevil, *Pachyrhynchus sonani* Kôono (Coleoptera, Curculionidae), from Green Island and Orchid Island populations. Wu *et al.* (2016) identified three distinct species within an endemic Taiwanese tree frog, *Kurixalus eiffingeri* (Boettger) (Anura, Rhacophoridae) based on adult and tadpole morphologies and molecular and behavioral traits (mating calls). These studies demonstrate the usefulness of integrating different data types for the discovery of cryptic species, and highlight that the biodiversity of islands like Taiwan may still be underestimated, even for well-studied taxa.

Our findings in this study also revealed that the spider diversity in Taiwan may be largely underestimated. We consider that insufficient investigation and the lack of a comprehensive taxonomic study of endemic fauna are the main reasons. For instance, the diversity of *Hamataliwa* Keyserling was also underestimated (unpublished data), as in the case of *Oxyopes*. To the best of our knowledge, this is the first study to delineate new spider species in Taiwan by combining morphological and genetic data with multiple molecular species delimitation methods. The results not only revealed the underestimation of *Oxyopes* diversity, but also indicated that integrated taxonomic studies can speed up the progress of characterizing endemic species in Taiwan.

Taxonomy

Family Oxyopidae Thorell, 1870

Genus *Oxyopes* Latreille, 1804

Diagnosis. Eyes are arranged in four rows with AER recurved and PER procurved. PME and PLE subequal in diameter, larger than AME but equal to or slightly smaller than ALE. Carapace high, uplifted, with face almost vertical. Chelicerae usually with two promarginal teeth, one retromarginal tooth. Legs thin and long, with numerous conspicuous, strong and erect spines. Epigyne usually sclerotized and thick on posterior margin. Cymbium without basal apophysis (Brady 1964; Deeleman-Reinhold 2009; Mukhtar 2013).

Key to *Oxyopes* species of Taiwan

1	Ratio of female abdomen length to width greater than 2.5 (Fig. 11a); apex of male cymbium longer than two-thirds the total cymbium length (Fig. 6c–e) 2
-	Ratio of female abdomen length to width smaller than 2.5 (Fig. 11c); apex of male cymbium shorter than two-thirds the total cymbium length (Fig. 7c–e) 5
2	Posterior edge of epigyne with a median protrusion (Figs 6a, 8a); male palp with two separate retrolateral tibial apophyses (Figs 6e, 8e) 3
-	Posterior edge of epigyne without a median protrusion (Fig. 3a) ; male palp with four or two adjacent retrolateral tibial apophyses (Fig. 3d) 4
3	Median protrusion of epigyne acuminate; cymbium of male palp laterally extended at the base (Figs 6a, 6d) . . . . . *O. macilentus*
-	Median protrusion of epigyne column-shaped; cymbium of male palp without lateral extension at the base (Figs 8a, 8d) . . . . . *O. striagatus*
4	Epigyne shield-like in shape; base of cymbium with a hamulus-like process (see Lo & Lin 2016: figs 5–7) . . . . . *O. shushilae*
-	Posterior edge of epigyne semi-ring shaped; basse of cymbium without lateral extension (Figs 3a, 3d) . . . . . *O. fujianicus*
5	Distal portion of copulatory ducts distinctly separated; dorsal retrolateral tibial apophysis spearhead-shaped and adjacent to ventral retrolateral tibial apophysis (Fig. 5d–e) . . . . . *O. hasta*
-	Copulatory ducts close distally; dorsal and ventral retrolateral tibial apophyses distinctly separated (Figs 7e, 10d–e) 6
6	Copulatory ducts with distal transversal twist; dorsal retrolateral tibial apophysis incisor tooth-shaped (Figs 9b-e) . . . . . *O. taiwanensis*
-	Copulatory ducts question mark-shaped and without distal transversal twist; dorsal retrolateral tibial apophysis ridge-shaped (Figs 7b-e) . . . . . *O. sertatus*

Species description

Oxyopes fujianicus Song & Zhu, 1993

Figs 3, 11a

Oxyopes fujianicus Song & Zhu, in Song *et al*., 1993: 875, fig. 43 (holotype: 1 male, Mt. longqi, Fujian, IZCAS, not examined); Song, *et al.* 1999: 399, figs 235E, 236D; Tang & Li 2012: 29, figs 27–28.
Oxyopes bianatinus Xie & Kim, 1996: 33, figs 1–5; Song *et al.* 1999: 399, figs 233I–J, 235A; Yin *et al*. 2012: 907, fig. 457.

Material examined. All specimens were collected from Taiwan.

1 male (TESRI Ar1357), 22 Jul. 2015, Ying-Yuan Lo leg., Jiuliaoxi Ecological Park, Yilan County (24°40′25.9″N, 121°35′54.3″E; 185 m elevation); 6 females (TESRI C04006–C04007, C04013, C04016, C04034–C04035) and 3 males (C04009, C04012, C04031), 06 Sep. 2015, Yi-Da Lai leg., Duona Forest Road, Kaohsiung City (22°53′16.9″N, 120°44′16.5″E; 1050 m elevation); 1 female (TESRI Ar2751), 28 Oct. 2017, Kuang-Ping Yu leg., Fenghuang Tea Garden, Nantou County (23°43′43.3″N, 120°47′16.9″E; 860 m elevation)

Diagnosis. *Oxyopes fujianicus* is similar to *O.lineatipes* (L. Koch, 1847) in genital morphology. However, it can be distinguished from the latter species by the following characters: (1) the male palp with four separate and differently shaped retrolateral apophyses (arranged closely, petal-like in *O. lineatipes*); (2) the copulatory duct twisted into "S" shape ("C" shape in *O. lineatipes*).

Description. Female (TESEI Ar1357). Total length 9.9; carapace length 3.3, width 2.5; abdomen length 6.6, width 2.3. *Carapace* yellowish-green, pear shaped, with two reddish-orange median lines from PME extended to posterior margin, two orange lines on each side. Fovea longitudinal. Clypeus high, with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.12, ALE 0.26, PME 0.24, PLE 0.24, eye size ALE > PME = PLE > AME; MOA-L 0.90, MOA-AW 0.40, MOA-PW 0.70; AME-I 0.16, PME-I 0.24, AML-I 0.08, PML-I 0.35; clypeus height 0.74. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endite and labium* longer than wide. *Sternum* yellowish with several setae. Proximal margins of coxa usually black. *Abdomen* fusiform, covered with scale-like patches. Dorsum cream yellow with three conspicuous reddish-orange, longitudinal stripes: central one is cardiac mark and others on each side (usually mottled) with a pair of black flecks at two-thirds along the stripe. Abdomen with irregularly meshed, lateral black band. In ventral view, broad dark longitudinal band extending from epigastric furrow to spinnerets. *Legs* clothed with many conspicuous long spines, with distinct black stripe on ventral femur I–III and dorsal tibia I–III. Three claws. Pedipalps bear apical claw. Measurements of pedipalps and legs: palp 3.7 (1.1, 0.5, 0.8, 1.3), leg I 18.3 (5.2, 1.1, 5.1, 5.3, 1.6), leg II 15.6 (4.5, 1.1, 4.0, 4.6, 1.4), leg III 10.8 (3.1, 0.8, 2.8, 3.2, 0.9), leg IV 12.3 (3.6, 0.8, 3.0, 3.9, 1.0). Leg formula: I > II > IV > III. *Epigyne* sclerotized, prominent on posterior edge to form semi-ring shape. Copulatory ducts twisted into "S" shape, spermathecae rounded, fertilization ducts slender and elongate.

Male (TESEI C04009). Body shape and coloration similar to female, but markings more variegated and abdomen thinner. Total length 6.9; carapace length 3.0, width 2.5; abdomen length 3.9, width 1.5. Eye diameters and interdistances: AME 0.12, ALE 0.26, PME 0.22, PLE 0.22, eye sizes ALE > PME = PLE > AME; MOA-L 0.96, MOA-AW 0.38, MOA-PW 0.64; AME-I 0.18, PME-I 0.24, AML-I 0.06, PML-I 0.26; clypeus height 0.50. Measurements of pedipalps and legs: pedipalp 3.8 (1.3, 0.4, 0.5, 1.6), leg I 18.0 (4.7, 1.1, 4.9, 5.4, 1.9), leg II 15.9 (4.2, 1.1, 4.3, 4.7, 1.6), leg III 13.2 (3.7, 1.0, 3.3, 4.0, 1.2), leg IV 15.1 (4.3, 1.0, 3.6, 4.8, 1.4). Leg formula: I > II □ IV > III. *Palp* tibia with a retrolateral depression and four separate and differently shaped apophyses: sharp-shaped apophysis on anterior margin, ridge-shaped one on ventral side, and two blunt, digit-shaped ones on posterior margin (Fig. 3d).

Size Variation. Three female and two male specimens were measured to quantify the morphological variations. Values are mean ± SD of females (with the male in parentheses). Total length 9.4 ± 0.4 (7.3 ± 0.5); cephalothorax length 3.1 ± 0.2 (3.1 ± 0.1), width 2.4 ± 0.1 (2.5 ± 0.0); abdomen length 6.4 ± 0.3 (4.2 ± 0.4), width 2.4 ± 0.2 (1.6 ± 0.1). Diameters of AME 0.11 ± 0.01 (0.12 ± 0.00), ALE 0.26 ± 0.00 (0.26 ± 0.00), PME 0.23 ± 0.01 (0.21 ± 0.01), PLE 0.23 ± 0.01 (0.21 ± 0.01). MOA-L 0.95 ± 0.05 (0.96 ± 0.00), MOA-AW 0.39 ± 0.01 (0.37 ± 0.01), MOA-PW 0.68 ± 0.02 (0.64 ± 0.00); AM-I 0.17 ± 0.03 (0.16 ± 0.03), PM-I 0.25 ± 0.01 (0.25 ± 0.01), AML-I 0.09 ± 0.01 (0.08 ± 0.03), PML-I 0.32 ± 0.03 (0.26 ± 0.00). Clypeus height 0.66 ± 0.09 (0.53 ± 0.04). Pedipalp 3.7 ± 0.1 (3.8 ± 0.0), leg I 17.4 ± 1.3 (18.1 ± 0.1), leg II 15.5 ± 0.2 (16.0 ± 0.1), leg III 12.0 ± 1.1 (13.3 ± 0.1), leg IV 13.9 ± 1.4 (15.2 ± 0.1).

Distribution. China (Song & Zhu, in Song *et al*. 1993) and Taiwan (newly recorded).

Remark. Although we did not examine the type specimen, the original description and illustrations are unequivocal to confirm that specimens from Taiwan belong to *O. fujianicus*.

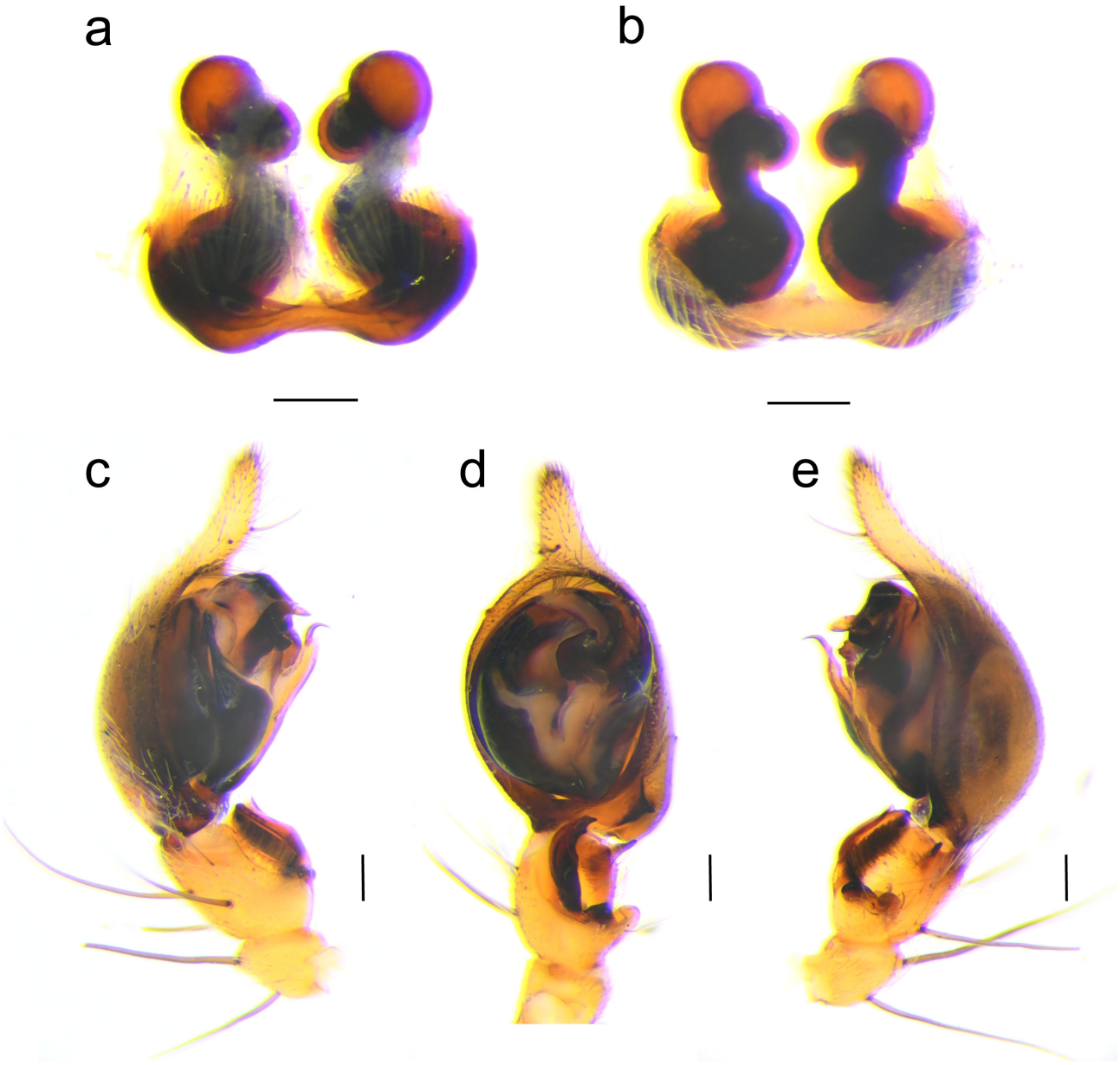

FIGURE 3. *Oxyopes fujianicus* Song & Zhu, 1993. (a–b) Epigyne (TESRI Ar1357): (a) ventral; (b) dorsal. (c–e) Palp (TESRI C04009): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

***Oxyopes hasta* sp. nov.**

Figs 4–5, 11b–d

Material examined. All specimens from Taiwan.

Holotype. 1 male (TESRI Ar2822), 17 May 2018, Ying-Yuan Lo leg., Jiufenershan, Nantou County (23°57′37.9″N, 120°50′59.2″E; 730 m elevation).

Paratype. 1 female (TESRI Ar0532), 14 Jan. 2014, Ying-Yuan Lo leg., Maolin Ecological Park, Kaohsiung City (22°53′14.6″N, 120°39′47.3″E; 290 m elevation); 2 females (TESRI Ar2881–2882), 17 May 2018, Ying-Yuan Lo leg., Jiufenershan, Nantou County (23°57′37.9″N, 120°50′59.2″E; 730 m elevation); 1 male (TESRI B03-1701026), 15 Apr. 2017, 1 female (TESRI B03-1702001), 25 Jun. 2017, Chen-Yao Lin leg., Chukou Nature Center, Jiayi County (23°27′11.3″N, 120°33′34.4″E; 193 m elevation).

Other material examined. 1 female (TESRI Ar0845), 26 Mar. 2014, Ying-Yuan Lo leg., 1 male (TESRI Ar0841), 28 May 2014, Ying-Yuan Lo leg., Jinlun Forest Road, Taitung County (22°31′57.7″N, 120°56′33.0″E; 70 m elevation); 2 females (TESRI Ar1290/1294), 31 May 2015, Ying-Yuan Lo leg., Juzishan, Taitung County (23°06′23.1″N, 121°21′36.4″E, 135 m elevation); 1 male (TESRI Ar2434), 23 Jun. 2017, Chung-Sheng Huang leg.; 1 female (TESRI Ar2769), Apr. 27 2018, Ying-Yuan Lo leg., 1 male (TESRI Ar2880), Jun. 21 2018, Xiao-Tian Chang leg., Jiufenershan, Nantou County (23°57′37.9″N, 120°50′59.2″E; 730 m elevation); 2 males (TESRI CX016–CX017), 11 May 2018, Ying-Yuan Lo leg., 2 females (TESRI CX040/046) and 4 males (TESRI CX041/047/050/059), 26 Jul. 2018, Ying-Yuan Lo leg., Zhongliao, Nantou County (23°51′59.3″N, 120°46′59.3″E, 200 m elevation); 1 male (TESRI Ar1430), 18 Jul. 2015, Ying-Yuan Lo leg., 1 female (TESRI Ar1557), 22 Jan. 2016, Hui-Ling Chen leg., 1 female (TESRI Ar1753), 4 Mar. 2016, Hui-Ling Chen leg., Jiji, Nantou County (23°49′38.9″N, 120°48′04.0″E; 250 m elevation); 1 female (TESRI Ar0948) and 1 male (TESRI Ar0964), 25 Jun. 2014, Ying-Yuan Lo leg., 1 female (TESRI Ar0971) and 1 male (TESRI Ar0970), 4 Jul. 2014, Ying-Yuan Lo leg., 1 male (TESRI Ar0999), 3 Sep. 2014, Ying-Yuan Lo leg., 1 female (TESRI Ar1084), 27 Nov. 2014, Ying-Yuan Lo leg., Qipan Village, Yunlin County (23°40′49.9″N, 120°36′49.4″E; 140 m elevation); 1 male (TESRI Ar2726), 28 Jan. 2018, Ying-Yuan Lo leg., Yuanshan, Yilan Country (24°43′22.6″N, 121°43′19.0″E, 20 m elevation)

Diagnosis. *Oxyopes hasta* is similar to *O. sertatus* and *O. taiwanensis* in body shape and coloration, as well as epigyne morphology. However, it can be distinguished from the latter two species by the following characters: (1) the cymbium possesses a slight retrolateral triangular expansion in the ventral view; (2) the dorsal retrolateral tibial apophysis of the male palp is spearhead-shaped; and (3) the pair of female copulatory ducts are more separated and more curved than those of *O. sertatus* and *O. taiwanensis* (Figs 6a-e).

Etymology. The specific name '*hasta*' is an adjective, referring to the spearhead-shaped dorsal retrolateral tibial apophysis.

Description. Female (TESRI Ar0532, Paratype). Total length 7.9; carapace length 3.1, width 2.3; abdomen length 4.8, width 2.5. *Carapace* greenish-orange, pear shaped with pair of brown lines extending from PME to posterior margin, pair of distinctive, larger dark patches on submargin. Fovea longitudinal. In dorsal view, eyes arranged in four rows with AER strongly recurved and PER strongly procurved. Clypeus high with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.1, ALE 0.22, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.98, MOA-AW 0.38, MOA-PW 0.64; AME-I 0.18, PME-I 0.30, AML-I 0.10, PML-I 0.34; clypeus height 0.62. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endite and labium* longer than wide. *Sternum* with scattered irregular markings and several pairs of black flecks on margin. Two dark stripes visible from post-margin of sternum extending to middle of coxae IV. *Abdomen* fusiform with distinct cardiac mark, ivory, longitudinal, central band. Lateral region black-brown with three slant, ivory stripes connecting with central band. In ventral view, broad dark longitudinal band extends from epigastric furrow to spinnerets. *Legs* clothed with many conspicuous long spines with deep black stripe and light stripe on venter of femur. Proximal margin of coxae black. Three claws. Pedipalps bear apical claw. Measurements of pedipalps and legs: pedipalp 3.14 (1.00, 0.36, 0.68, 1.10), leg I 11.6 (3.2, 4.1, 3.0, 1.3), leg II 10.7 (3.0, 3.8, 2.8, 1.1), leg III 8.9 (2.7, 2.9, 2.4, 0.9), leg IV 10.4 (3.0, 3.4, 3.0, 1.0). Leg formula: I > II ≒ IV > III. *Epigyne* with central depression. Posterior edge sclerotized, incrassate. Copulatory ducts thick, curved intensely (Fig. 5b). Spermathecae rounded. Fertilization ducts slender, elongate backward with hook-like terminal.

Male (TESRI Ar2822, Holotype). Body shape and color pattern similar to that of female, but markings more variegated and abdomen thinner. Total length 6.5; carapace length 3.3, width 2.4; abdomen length 3.2, width 1.6. Eye diameters and inter-distances: AME 0.14, ALE 0.22, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.94, MOA-AW 0.38, MOA-PW 0.64; AME-I 0.12, PME-I 0.32, AML-I 0.06, PML-I 0.34; clypeus height 0.64. Measurements of pedipalps and legs: pedipalp 3.8 (1.2, 0.4, 0.6, 1.6), leg I 13.8 (3.5, 1.1, 3.6, 3.8, 1.8), leg II 12.6 (3.2, 1.1, 3.3, 3.6, 1.4), leg III 10.8 (3.0, 1.0, 2.5, 3.2, 1.1), leg IV 12.3 (3.4, 1.0, 2.8, 3.8, 1.3). Leg formula: I > II ≒ IV > III. *Palp* tibia with distinct retrolateral depression, two adjacent apophyses: dorsal retrolateral tibial apophysis large and spearhead-shaped; ventral retrolateral tibial apophysis smaller, ridge-shaped, with two irregular protrusions (Fig. 5d). Cymbium with slight triangular extension on retrolateral side in ventral view. Conductor black, sclerotized with bent apex and large incision. Embolus slender, originating at 7 o'clock position and encompassing prolateral side of genital bulb to 1 o'clock position, apex covered by conductor. Median apophysis white, laminar.

Size Variation. Three female and five male specimens were measured to quantify the morphological variations. Values are mean ± SD of females (with the male in parentheses). Total length 8.3 ± 0.6 (6.0 ± 0.3); cephalothorax length 3.1 ± 0.1 (2.9 ± 0.3), width 2.4 ± 0.1 (2.2 ± 0.1); abdomen length 5.2 ± 0.5 (3.1 ± 0.1), width 3.0 ± 0.6 (1.5 ± 0.1). Diameters of AME 0.11 ± 0.01 (0.12 ± 0.01), ALE 0.23 ± 0.01 (0.22 ± 0.01), PME 0.19 ± 0.01 (0.18 ± 0.02), PLE 0.19 ± 0.01 (0.18 ± 0.02). MOA-L 0.97 ± 0.03 (0.86 ± 0.05), MOA-AW 0.38 ± 0.02 (0.36 ± 0.02), MOA-PW 0.67 ± 0.03 (0.59 ± 0.04); AME-I 0.17 ± 0.04 (0.12 ± 0.01), PME-I 0.29 ± 0.01 (0.25 ± 0.04), AML-I 0.09 ± 0.01 (0.06 ± 0.00), PML-I 0.30 ± 0.05 (0.28 ± 0.04). Clypeus height 0.61 ± 0.01 (0.58 ± 0.06). Pedipalp 3.1 ± 0.1 (3.4 ± 0.3), leg I 11.4 ± 0.3 (12.0 ± 1.3), leg II 10.5 ± 0.2 (11.1 ± 1.0), leg III 8.9 ± 0.3 (9.2 ± 1.1); leg IV 10.4 ± 0.2 (10.6 ± 1.1).

Distribution. Endemic to Taiwan.

Remark. *Oxyopes hasta* is similar to *O. sertatus* in body size and color pattern and usually inhabits the same habitats, such as grasslands and bush fallows, in Taiwan. However, *O. hasta* occurs almost exclusively in southwestern and southeastern Taiwan and its coloration is deeper, while *O. sertatus* is widespread on the island and its coloration is lighter. We surveyed the literature on *Oxyopes* from adjacent region of Taiwan, and did not find described species that could be confounded with *O. hasta*.

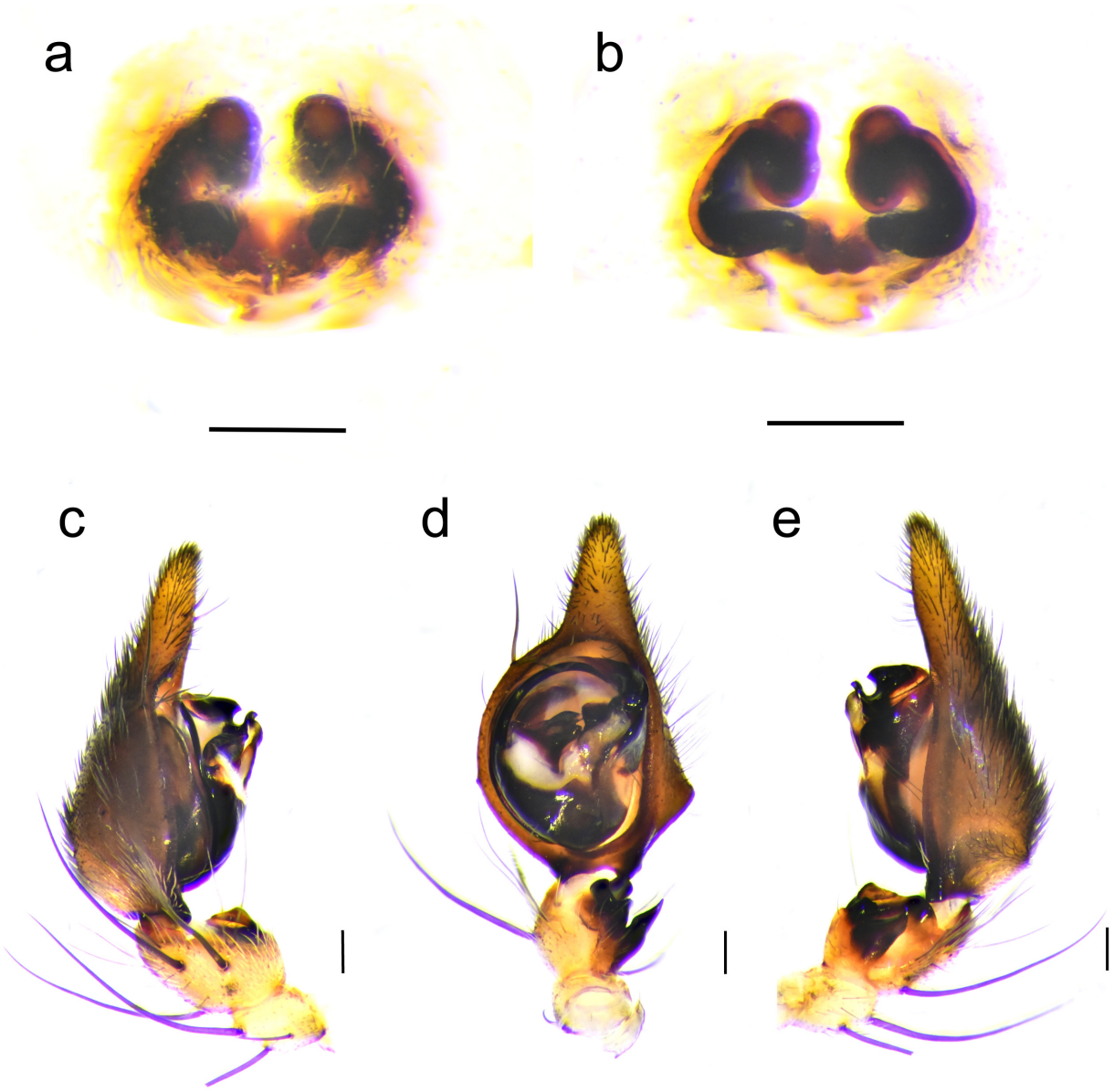

FIGURE 4. *Oxyopes hasta* **sp. nov.** (a–b) Epigyne (TESRI Ar0532): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar2434): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

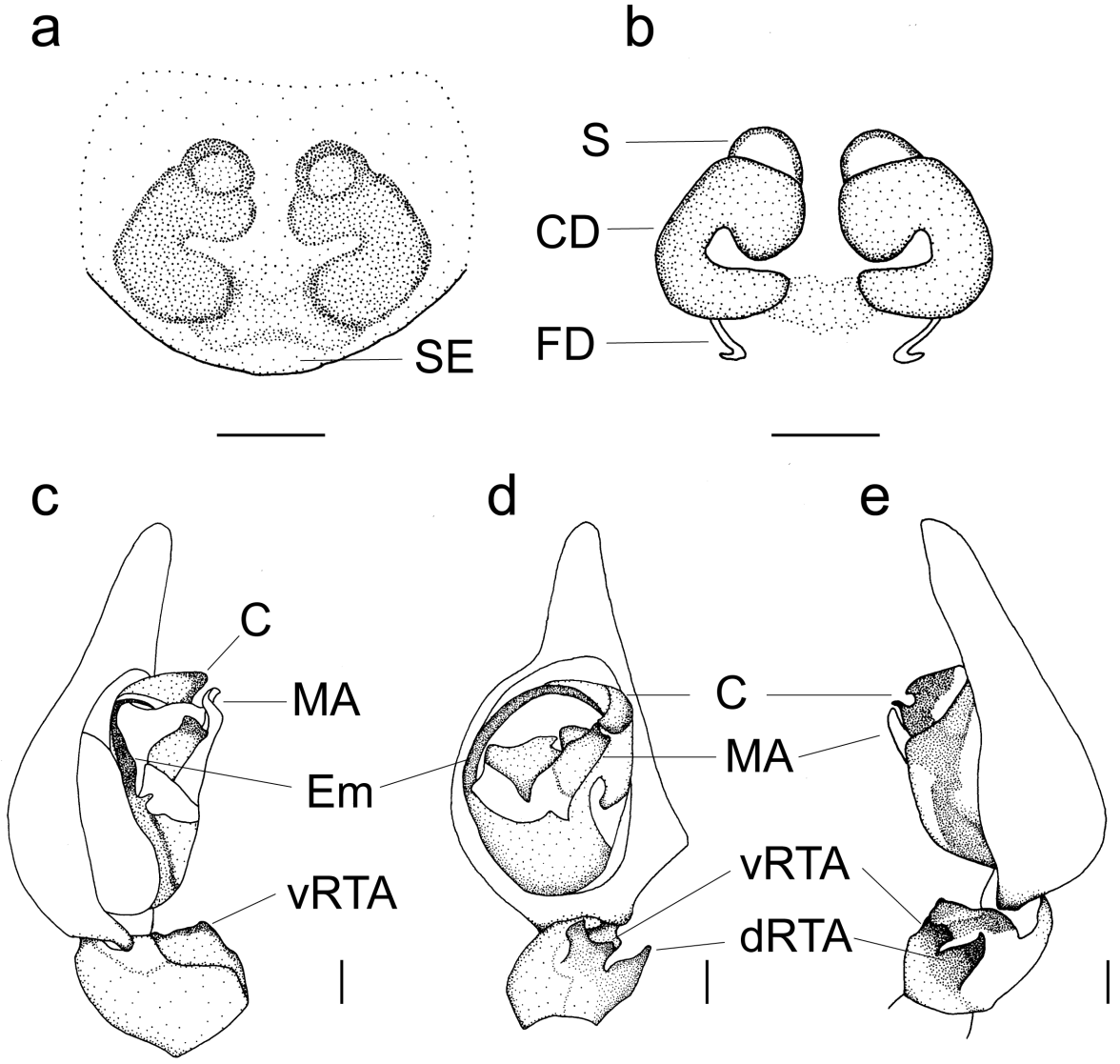

FIGURE 5. *Oxyopes hasta* **sp. nov.** (a–b) Epigyne (TESRI Ar0532): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar2822): (c) prolateral; (d) ventral; (e) retrolateral. **C**: conductor; **CD**: copulatory duct; **dRTA**: dorsal retrolateral tibial apophysis; **Em**: embolus; **MA**: median apophysis; **FD**: fertilization duct; **S**: spermatheca; **SE**: sclerotized edge; **vRTA**: ventral retrolateral tibial apophysis. Scale bars: 0.2 mm.

Oxyopes macilentus Koch, 1878

Figs 6, 12a–b

Oxyopes macilentus L. Koch, 1878a: 1000, pl. 87, figs 4–5; Song 1991: 173, fig. 5; Song *et al*., 1993: 876, fig. 45; Hu 2001: 223, figs 119.1–2; Ono & Ban 2009: 250, figs 9–11; Baehr *et al*. 2017: 23, figs 10, 21. (Lectotype: 1 female, designated by Baehr *et al.* 2017, from Rockhampton, Queensland, Australia, ZMH, not examined).

Material examined. All specimens were collected from Taiwan.

1 female (TESRI Ar1298), 30 Mar. 2015, Ying-Yuan Lo leg., Jinlun Forest Road, Taitung County (22°31′57.7″N, 120°56′33.0″E; 70 m elevation); 2 females (TESRI Ar1566/2774) and 4 males (TESRI Ar1765/2775–2777), 17 Mar. 2016, Ying-Yuan Lo leg., Daduhua, Hualian County (23°33′16.1″N, 121°24′11.1″E; 210 m elevation); 1 fe-

male (TESRI Ar1890) and 1 male (TESRI Ar1889), 30 Aug. 2016, Ying-Yuan Lo leg., Baibaoxi, Hualian County (23°53′18.0″N, 121°30′11.2″E; 100 m elevation); 1 female (TESRI Ar1571) and 1 male (TESRI Ar1572), 18 Mar. 2016, Ying-Yuan Lo leg., Qimei Village, Hualien County (23°29′41.8″N, 121°26′27.8″E; 70 m elevation); 2 females and 1 male (TESRI Ar1364–1366), 20 Jul. 2015, Ying-Yuan Lo Leg., Shikong Historical Trail, Yilan County (24°52′56.5″N, 121°50′37.8″E; 20 m elevation); 2 males (TESRI Ar1603/1652), 31 Mar. 2016, Ying-Yuan Lo leg., 4 females (TESRI Ar2089–2092), 10 Aug. 2016, Chung-Sheng Huang leg., Jiufenershan, Nantou County (23°57′37.9″N, 120°50′59.2″E; 730 m elevation); 1 female (TESRI Ar0524), 26 Apr. 2013, Ying-Yuan Lo leg., Jiji, Nantou County (23°49′38.9″N, 120°48′04.0″E; 250 m elevation); 1 male (TESRI Ar0517), 07 Jun. 2013, Eugene Tsao leg., Laofoshan, Pingtung County (22°02′21.6″N, 120°47′27.8″E; 640 m elevation); 1 female (TESRI C02175), 4 Nov. 2017, Guo-Yuan Wu leg., 1 male (TESRI Ar2762), 8 Jun. 2018, Guo-Yuan Wu leg., 1 female (TESRI CS041), 4 Aug. 2018, Guo-Yuan Wu leg., Shoushan National Nature Park, Kaohsiung City (22°39′19.1″N, 120°16′09.0″E, 75 m elevation); 2 females (TESRI Ar0802/0813) and 1 male (TESRI Ar0770), 22–23 Apr. 2014, Ying-Yuan Lo leg., 2 females (TESRI Ar0893/0896) and 1 male (TESRI Ar0895), 25–26 Jun. 2014, Ying-Yuan Lo leg., 7 females (TESRI Ar1051–1052/1126/1107–1108/1118–1119), 20–22 Oct. 2014, Ying-Yuan Lo leg., Qipan Village, Yunlin County (23°40′49.9″N, 120°36′49.4″E; 140 m elevation); 1 female (TESRI A05058), 29 May. 2015, Da-Ching Chang leg., Changxing Road, New Taipei City (24°56′23.4″N, 121°33′15.1″E, 130 m elevation); 1 female (TESRI Ar2771), 31 Mar. 2018, Ying-Yuan Lo leg., Pinglin Tea Garden, New Taipei City (24°55′51.5″N, 121°42′20.1″E, 200 m elevation); 1 male (TESRI Ar2748), 19 Sep. 2016, Kuang-Ping Yu leg., National Taiwan University, Taipei City (25°01′03.4″N, 121°32′23.3″E, 15 m elevation); 1 female (TESRI Ar2759) and 1 male (TESRI Ar2758), 27 Jun. 2018, Yi-Lun Lin leg., Orchid Island, Taitung County (22°01′44.7″N, 121°34′43.3″E; 18 m elevation).

Diagnosis. *Oxyopes macilentus* is similar to *O. striagatus* in body shape and coloration, as well as genital morphology. However, it can be distinguished from the latter species by the following characters: (1) the distal median protrusion of epigyne is acuminate (columnar in *O. striagatus*); (2) the base of male cymbium is laterally extended (without lateral extension in *O. striagatus*).

Description. Female (TESRI CS041). Total length 6.5; carapace length 2.5, width 2.0; abdomen length 4.0, width 1.5. *Carapace* yellowish-green, pear-shaped, with two brown central lines from PME extending to posterior margin, pair of bands on submargin. Fovea longitudinal. Clypeus high, with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.10, ALE 0.20, PME 0.16, PLE 0.16, eye sizes ALE > PME = PLE > AME; MOA-L 0.78, MOA-AW 0.34, MOA-PW 0.52; AME-I 0.16, PME-I 0.22, AML-I 0.04, PML-I 0.24; clypeus height 0.48. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endite and labium* longer than wide. *Sternum* yellowish with irregular flecks on margin and several hairs. *Abdomen* fusiform, yellowish-green. Cardiac mark reddish-brown with black lines on each lateral margin. Lateral abdomen pale white with two parallel black stripes. In ventral view, broad dark longitudinal band extending from epigastric furrow to spinnerets. *Legs* clothed with many conspicuous long spines, distinct black stripes on venter of femur I–III and dorsum of tibia I–III. Three claws. Pedipalps bear apical claw. Measurements of pedipalps and legs: pedipalp 2.9 (0.9, 0.4, 0.6, 1.0), leg I 12.2 (3.3, 0.8, 3.4, 3., 1.3), leg II 11.2 (3.1, 0.8, 3.0, 3.2, 1.1), leg III 9.3 (2.7, 0.8, 2.3, 2.6, 0.9), leg IV 10.9 (3.1, 0.8, 2.7, 3.3, 1.0). Leg formula: I > II ≒ IV > III. *Epigyne* sclerotized on posterior edge with median acuminate-shaped projection. Copulatory ducts thick, curved, with rounded spermathecae on apical side. Fertilization ducts slender, elongate, with hook-like terminals.

Male (TESRI Ar2762). Body shape and coloration are similar to that of female, but markings more variegated and abdomen thinner. Total length 5.5; carapace length 2.3, width 1.9; abdomen length 3.2, width 1.1. Eye diameters and inter-distances: AME 0.10, ALE 0.20, PME 0.16, PLE 0.16, eye sizes ALE > PME = PLE > AME; MOA-L 0.70, MOA-AW 0.30, MOA-PW 0.46; AME-I 0.12, PME-I 0.18, AML-I 0.04, PML-I 0.20; clypeus height 0.40. Measurements of pedipalps and legs: pedipalp 3.1 (1.0, 0.3, 0.4, 1.4), leg I 12.4 (3.1, 0.7, 3.4, 3.7, 1.5), leg II 11.4 (3.0, 0.8, 3.0, 3.4, 1.2), leg III 9.3 (2.6, 0.8, 2.2, 2.8, 0.9), leg IV 11.1 (3.0, 0.8, 2.7, 3.6, 1.0). Leg formula: I > II ≒ IV > III. *Palp* tibia with two retrolateral apophyses: ventral retrolateral tibial apophysis longitudinal, dorsal retrolateral tibial apophysis oblique. In ventral view, two apophyses connect with each other and form an arc shape. Cymbium with a basal extension on retrolateral side.

Size Variation. Three female and three male specimens were measured to quantify the morphological variation. Values are mean ± SD of females (with the male in parentheses). Total length 6.1 ± 0.4 (5.5 ± 0.5); cephalothorax length 2.5 ± 0.1 (2.4 ± 0.1), width 1.9 ± 0.1 (1.8 ± 0.1); abdomen length 3.7 ± 0.3 (3.2 ± 0.2), width 1.4 ± 0.1 (1.2 ±

0.1). Diameters of AME 0.11 ± 0.01 (0.10 ± 0.00), ALE 0.21 ± 0.01 (0.19 ± 0.01), PME 0.17 ± 0.01 (0.15 ± 0.01), PLE 0.17 ± 0.01 (0.15 ± 0.01). MOA-L 0.79 ± 0.04 (0.73 ± 0.06), MOA-AW 0.34 ± 0.00 (0.30 ± 0.02), MOA-PW 0.52 ± 0.00 (0.47 ± 0.03); AME-I 0.15 ± 0.01 (0.13 ± 0.01), PME-I 0.22 ± 0.00 (0.18 ± 0.02), AML-I 0.05 ± 0.01 (0.05 ± 0.01), PML-I 0.25 ± 0.01 (0.21 ± 0.02). Clypeus height 0.46 ± 0.02 (0.41 ± 0.05). Pedipalp 3.1 ± 0.3 (3.0 ± 0.1), leg I 12.3 ± 0.6 (12.0 ± 0.8), leg II 11.2 ± 0.6 (11.2 ± 0.3), leg III 9.2 ± 0.6 (9.2 ± 0.1), leg IV 10.9 ± 0.8 (11.0 ± 0.1).

Distribution. Japan, China, Taiwan to Australia (Hu 1984; Ono & Ban 2009; Baehr *et al*. 2017).

Remark. Baehr *et al*. (2017) re-examined the syntypes of *O. macilentus* deignsted by Koch (1878a) and designated a lectotype. The description and illustration of *O. macilentus* in this report is helpful for clarifying the species from Taiwan because a few earlier illustrations and descriptions were ambiguous (Lee 1964) and could lead to confusion. Chu & Okuma (1970) surveyed spiders in paddy fields and first recorded *O. macilentus* from Taiwan. However, no illustrations nor descriptions were provided in this report. We examined the morphology of both male and female specimens of *O. macilentus* recently collected from Taiwan, and found that these specimens are consistent with the photographs and description in Baehr *et al*. (2017).

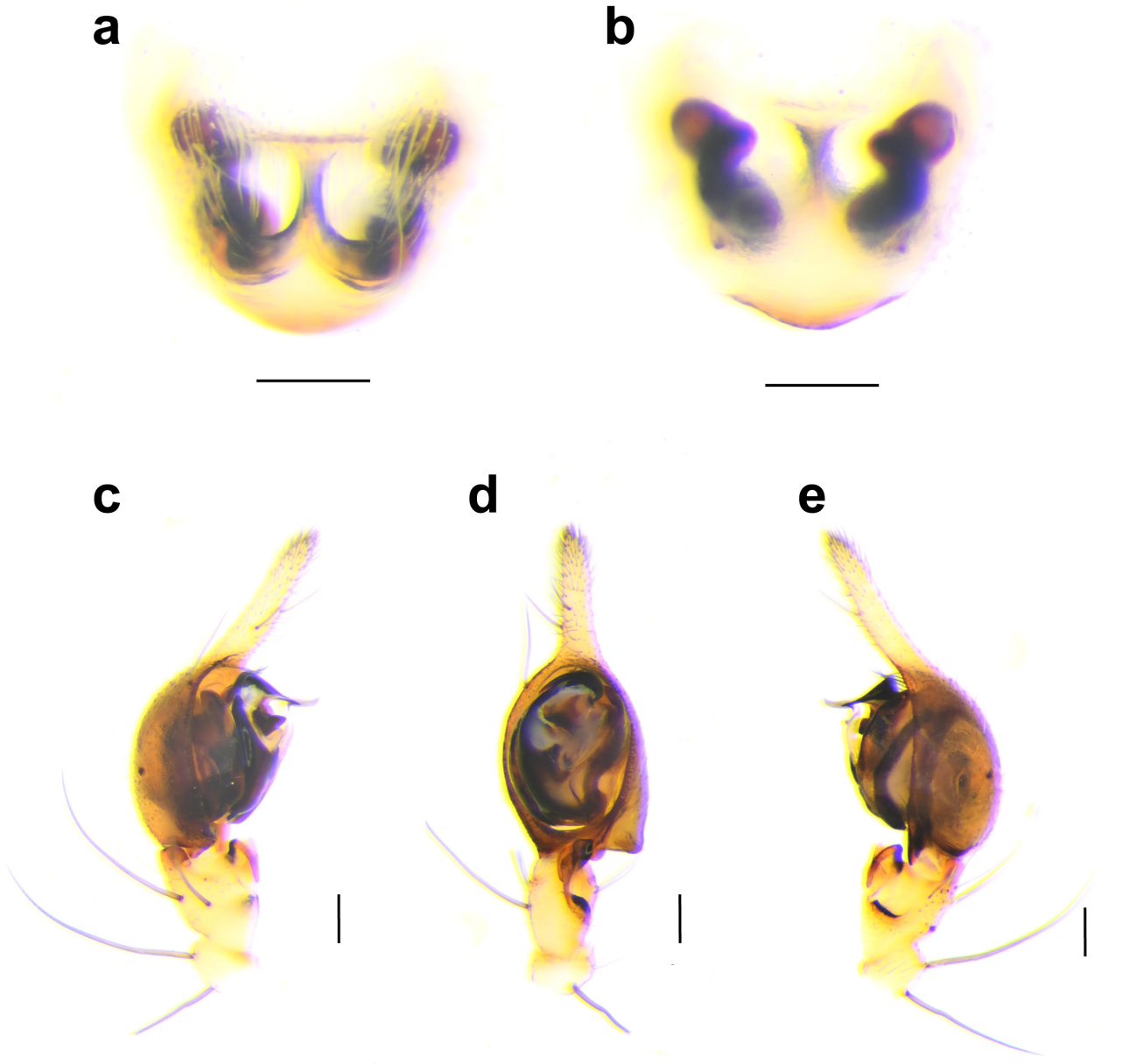

FIGURE 6. *Oxyopes macilentus* L. Koch, 1878. (a–b) Epigyne (TESRI CS041): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar2762): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

***Oxyopes sertatus* Koch, 1878**
Figs 7, 12

Oxyopes sertatus L. Koch, 1878b: 779 (holotype: Immature female from Japan, possibly deposited in the Natural History Museum, London [Sherriffs 1955: 304], not examined); Bösenberg & Strand 1906: 327, pl. 8, fig. 117, pl. 15, fig. 435; Lee 1964: 63, fig. 23(a–c); Hu 1984: 271, fig. 287; Xie & Kim 1996: 36, figs 15–16; Ono & Ban 2009: 249, figs 1–5; Yin *et al*. 2012: 917, fig. 464.
Argiope aequior Chamberlin 1924: 16, pl. 4, fig. 33.

Diagnosis. *Oxyopes sertatus* is similar to *O. sertatoides* Xie & Kim, 1996 in genital morphology. However, it can be distinguished from the latter species by the following characters: (1) the dorsal retrolateral tibial apophysis of male palp is longitudinal and ridge-shaped, without a triangular black outgrowth (with a triangular outgrowth in *O. sertatoides*); (2) the copulatory duct is question mark-shaped, without distally transversal twist (curved and with distally transversal twist in *O. sertatoides*).

Material examined. CHINA: 1 female (TESRI Ar2764), 29 May 2018, Hua Zeng leg., Hainan Island. TAIWAN: 1 female (TESRI Ar0890) and 2 males (TESRI Ar0891–0892), 27 Jun. 2014, Ying-Yuan Lo leg., Dakeng, Taichung City (24°10′26.3″N, 120°46′54.9″E, 430 m elevation); 6 females (TESRI Ar1523–1528) and 3 males (TESRI Ar1520–1522), 09 Apr. 2015, Ying-Yuan Lo leg., Wushikeng Experimental Station, Taichung City (24°16′27.5″N, 120°56′53.8″E, 990 m elevation); 1 female (TESRI Ar1336), 27 Jun. 2015, Ying-Yuan Lo leg., Taipei Zoo, Taipei City (24°59′36.6″N, 121°34′51.9″E, 70 m elevation); 2 females (TESRI YMS049–YMS050) and 1 male (TESRI YMS038), 30 Jun. 2017, Li-Jing Huang leg., Pamier Park, Taipei City (25°07′20.4″N, 121°35′37.0″E; 350 m elevation); 2 males (TESRI Ar1287–1288), 30 Mar. 2015, Ying-Yuan Lo leg., Jinlun Forest Road, Taitung County (22°31′57.7″N, 120°56′33.0″E; 70 m elevation); 2 females (TESRI Ar1293/1295) and 2 males (TESRI Ar1291–1292), 31 May 2015, Ying-Yuan Lo leg., Juzishan, Taitung County (23°06′23.1″N, 121°21′36.4″E, 135 m elevation); 4 females (TESRI Ar1358/1361–1363) and 2 males (TESRI Ar1359–1360), 20 Jul. 2015, Ying-Yuan Lo Leg., Shikong Historical Trail, Yilan County (24°52′56.5″N, 121°50′37.8″E; 20 m elevation); 1 female (TESRI Ar2442), 08 Jun. 2017, Chung-Sheng Huang leg., Paoma Historical Trail, Yilan County (24°50′26.7″N, 121°46′20.4″E, 250 m elevation); 2 females (TESRI Ar1325–1326) and 1 male (TESRI Ar1324), 15 May 2015, Ying-Yuan Lo leg., Daduhua, Hualian County (23°33′16.1″N, 121°24′11.1″E; 210 m elevation); 2 females (TESRI Ar1906–1907) and 2 males (TESRI Ar1904–1905), 31 Aug. 2016, Ying-Yuan Lo leg., Tongmen Bridge, Hualian County (23°57′52.6″N, 121°29′56.8″E, 170 m elevation); 2 males (TESRI Ar1689–1690), 30 Mar. 2016, Ying-Yuan Lo leg., 2 females (TESRI Ar2270/2305), 27 Mar. 2017, Chung-Sheng Huang leg., Jiufenershan, Nantou County (23°57′37.9″N, 120°50′59.2″E; 730 m elevation); 1 female (TESRI Ar0911), 10 Apr. 2014, Ying-Yuan Lo leg., Taomikeng, Nantou County (23°56′33.0″N, 120°56′01.2″E, 465 m elevation); 1 male (TESRI CX015), 11 May 2018, Ying-Yuan Lo leg., Zhongliao, Nantou County (23°51′59.3″N, 120°46′59.3″E, 200 m elevation); 3 females (TESRI Ar1531–1533) and 2 males (TESRI Ar1529–1530), 17 Apr. 2015, Ying-Yuan Lo leg., 1 male (TESRI Ar1774), 29 Apr. 2016, Hui-Ling Chen leg., Jiji, Nantou County (23°49′38.9″N, 120°48′04.0″E; 250 m elevation); 1 male (TESRI Ar1692), 27 Jan. 2016, Ying-Yuan Lo leg. (matured in 08 Mar. 2016), Fenghuanggu Bird and Ecological Park, Nantou County (23°43′45.7″N, 120°47′30.2″E, 790 m elevation); 1 female (TESRI Ar0440), 01 Jun. 2013, Jia-Wen Ke leg., Lianhuachi, Nantou County (23°55′06.4″N, 120°53′04.3″E, 685 m elevation); 1 male (TESRI Ar0516), 24 Apr. 2013, Ying-Yuan Lo leg., Shitoushan, Miaoli County (24°38′03.1″N, 121°01′02.4″E, 190 m elevation); 2 females (TESRI Ar0486/0527), 25 Apr. 2013, Ying-Yuan Lo leg., Mingfeng Historical Trail, Miaoli County (24°32′38.8″N, 120°55′09.4″E, 215 m elevation); 6 females (TESRI Ar0344–0347, 0521–0522) and 3 males (TESRI Ar0339–0341), 18 Apr. 2013, Ying-Yuan Lo leg., Sanmin, Taoyuan City (24°50′16.9″N, 121°20′35.6″E, 335 m elevation); 1 female (TESRI Ar0326), 17 Apr. 2013, Ying-Yuan Lo leg., Bade Pond Ecology Park, Taoyuan City (24°56′34.1″N, 121°18′41.4″E, 130 m elevation); 2 females (TESRI C02121–C02122) and 3 males (TESRI C02123/C02140/C02150, CS061), 10–14 Jun. 2016, Guo-Yuan Wu leg., Shoushan National Nature Park, Kaohsiung City, (22°39′19.1″N, 120°16′09.0″E, 75 m elevation); 1 male (TESRI Ar0321), 03 Sep. 2013, Jia-Wen Ke leg., Niaosong Wetland Park, Kaohsiung City (22°39′07.8″N, 120°21′04.0″E, 15 m elevation); 1 female (TESRI Ar0790) and 7 males (TESRI Ar0763–0764/0777–0778/0803–0805), 22–23 Apr. 2014, Ying-Yuan Lo leg., 1 female (TESRI Ar0894), 25 Jun. 2014, Ying-Yuan Lo leg., Qipan Village, Yunlin County (23°40′49.9″N, 120°36′49.4″E; 140 m elevation); 1 male (TESRI Ar2749), 30 Aug. 2016, Han-Po Chang leg., Niugangleng Hiking Trail, New Taipei City (25°07′56.6″N, 121°24′58.5″E, 335 m elevation); 1 female (TESRI A05050) and 1 male (TESRI A05009), 29 Aug.

2015, Da-Ching Chang leg., Changxing Road, New Taipei City (24°56′23.4″N, 121°33′15.1″E, 130 m elevation); 1 female (TESRI Ar0473), 01 Aug. 2013, Ying-Yuan Lo leg., Daqidong Trail, Hsinchu County (24°41′56.3″N, 121°08′24.5″E, 445 m elevation); 2 females (TESRI B02010–B02011) and 1 male (TESRI B02006), 12 Aug. 2015, De-Lun Wu leg., Lantan Trail, Chiayi City (23°28′36.9″N, 120°29′42.8″E, 100 m elevation); 1 female (TESRI B03002), 21 Aug. 2015, Chen-Yao Lin leg., Chukou Nature Center, Jiayi County (23°27′11.3″N, 120°33′34.4″E; 193 m elevation).

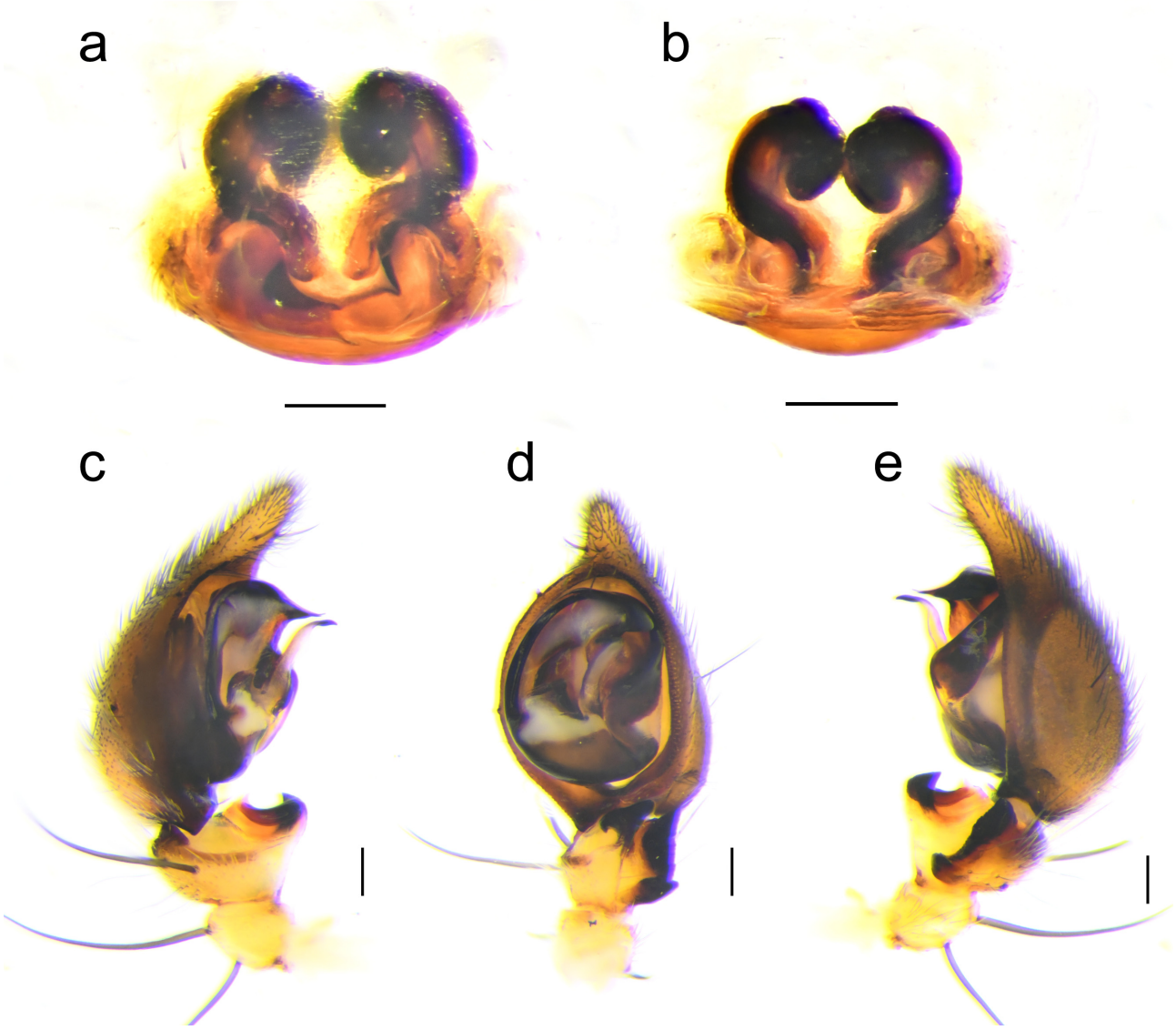

FIGURE 7. *Oxyopes sertatus* L. Koch, 1878. (a–b) Epigyne (TESRI Ar0440): (a) ventral; (b) dorsal. (c–e) Palp (TESRI CS-061): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

Description. Female (Ar0440). Total length 8.6; carapace length 3.4, width 2.6; abdomen length 5.2, width 2.8. *Carapace* yellowish-green, pear-shaped, with two brown central lines from PME extending to posterior margin, pair of broader, dark, mottled bands on submargin. Fovea longitudinal. Clypeus high, with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.12, ALE 0.24, PME 0.22, PLE 0.22, eye sizes ALE > PME = PLE > AME; MOA-L 1.08, MOA-AW 0.42, MOA-PW 0.74; AME-I 0.22, PME-I 0.34, AML-I 0.08, PML-I 0.36; clypeus height 0.75. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endite and labium* longer than wide. *Sternum* yellowish with several hairs. *Abdomen* fusiform, with distinct ivory, broad, longitudinal central band. Cardiac mark on central band with brown margin. Lateral region black-brown with three slant, ivory stripes connecting with central band. In ventral view, broad dark longitudinal band extending from epigastric furrow to spinnerets. *Legs* clothed with many conspicuous long spines, with deep black stripe on ventral femur I–III. Proximal margin of coxae black. Two claws. Pedipalps

bear apical claw. Measurements of pedipalp and legs: pedipalp 3.5 (1.0, 0.5, 0.8, 1.2), leg I 13.3 (3.7, 1.1, 3.5, 3.6, 1.4), leg II 12.3 (3.5, 1.1, 3.2, 3.3, 1.2), leg III 10.3 (3.1, 1.0, 2.4, 2.9, 0.9), leg IV 12.0 (3.5, 1.0, 2.8, 3.6, 1.1). Leg formula: I > II ≒ IV > III. *Epigyne* sclerotized on posterior edge with incrassate lateral side. Pair of spermatheca noticeable through exoskeleton in ventral view. Copulatory ducts thick, curved, question mark-shaped with rounded spermathecae on apical side. Fertilization ducts slender with hooked extremity.

Male (TESRI CS061). Body shape and coloration similar to that of female, but markings more variegated and abdomen thinner. Total length 5.8; carapace length 2.8, width 2.2; abdomen length 3.0, width 1.3. Eye diameters and inter-distances: AME 0.10, ALE 0.22, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.84, MOA-AW 0.34, MOA-PW 0.56; AME-I 0.16, PME-I 0.24, AML-I 0.06, PML-I 0.26; clypeus height 0.50. Measurements of pedipalp and legs: pedipalp 3.4 (1.0, 0.4, 0.5, 1.5), leg I 12.4 (3.1, 0.9, 3.2, 3.6, 1.6), leg II 11.4 (3.0, 0.9, 3.0, 3.3, 1.2), leg III 9.1 (2.5, 0.8, 2.1, 2.8, 0.9), leg IV 10.8 (2.9, 0.9, 2.5, 3.5, 1.0). Leg formula: I > II > IV > III. *Palp* tibia with two retrolateral, separate apophyses: dorsal retrolateral tibial apophysis longitudinal, ridge shaped with several transversal notches; ventral retrolateral tibial apophysis protrudes ventrally with triangular terminal pointing lateral-anteriorly.

Size Variation. Three female and four male specimens were measured to quantify the morphological variation. Values are mean ± SD of females (with males in parentheses). Total length 7.8 ± 0.8 (6.5 ± 0.5); cephalothorax length 3.3 ± 0.1 (3.1 ± 0.2), width 2.4 ± 0.2 (2.5 ± 0.3); abdomen length 4.4 ± 0.7 (3.4 ± 0.3), width 2.4 ± 0.4 (1.6 ± 0.2). Diameters of AME 0.12 ± 0.00 (0.11 ± 0.01), ALE 0.25 ± 0.01 (0.23 ± 0.01), PME 0.21 ± 0.01 (0.19 ± 0.01), PLE 0.21 ± 0.01 (0.19 ± 0.01). MOA-L 1.03 ± 0.04 (0.90 ± 0.04), MOA-AW 0.41 ± 0.01 (0.38 ± 0.03), MOA-PW 0.71 ± 0.03 (0.61 ± 0.04); AME-I 0.19 ± 0.03 (0.18 ± 0.01), PME-I 0.31 ± 0.03 (0.26 ± 0.02), AML-I 0.08 ± 0.00 (0.07 ± 0.01), PML-I 0.34 ± 0.03 (0.31 ± 0.03). Clypeus height 0.71 ± 0.04 (0.60 ± 0.08). Pedipalp 3.3 ± 0.2 (3.6 ± 0.2), leg I 12.9 ± 0.4 (13.6 ± 1.6), leg II 11.9 ± 0.3 (12.3 ± 1.3), leg III 9.9 ± 0.4 (10.1 ± 1.1), leg IV 11.7 ± 0.3 (11.5 ± 1.0).

Distribution. Japan, Korea, China (Hu 1984; Ono & Ban 2009; Kim & Lee 2017), and Taiwan.

Remark. *Oxyopes sertatus* was first described based on an immature female (Koch 1878b), then the male and female were described by Bösenberg & Strand (1906) from Japan. However, the illustrations and descriptions from both were not sufficient for proper species identification, and we did not examine the type specimen because of the uncertainty regarding its depository institution. In spite of these restrictions, the following studies are helpful to confirm that specimens from Taiwan belong to *O. sertatus* (Chamberlin 1924; Yaginuma 1960; Lee 1964; Paik 1969; Hu 1980). *O. sertatus* was first recorded from Taiwan by Saito (1933). Later, Lee (1964) provided a more detailed description and presented an illustration of the genitals. It mainly inhabits herbaceous vegetation, bush fallows, and grasslands by the edges of forests or open fields. In Taiwan, this species can be found in parks, paddy fields, tea farms, and orchards.

Oxyopes striagatus Song, 1991

Figs 8, 12e

Oxyopes striagatus Song, 1991: 174, fig. 6A–D (Holotype: 1 female, Sanmen, Zhejiang, China, 1978 VII 15, depository not informed, possibly at Institute of Zoology, Chinese Academy of Sciences, Beijing, not examined). Song *et al.* 1997: 1725, fig. 31a–d; Song *et al.* 1999: 401, figs 234Q–R, 235J, 237C; Yin *et al*. 2012: 918, fig. 465A–E.

Material examined. All specimens from Taiwan.

1 female (TESRI A05030), 29 Aug. 2015, Da-Ching Chang leg., Changxing Road, New Taipei City (24°56′23.4″N, 121°33′15.1″E, 130 m elevation); 2 females (TESRI Ar1439/1442), 12–13 Aug. 2015, Kuang-Ping Yu leg., Wushikeng Experimental Station, Taichung City (24°16′27.5″N, 120°56′53.8″E, 990 m elevation); 1 female (TESRI C04011) and 4 males (TESRI C04008/C04010/C04024/C04041), 06 Sep. 2015, Yi-Da Lai leg., 1 female (TESRI C04068) and 1 male (TESRI C04074), 12 Mar. 2016, 1 male (TESRI Ar1758), 14 Mar. 2016, Yi-Da Lai leg., Duona Forest Road, Kaohsiung City (22°53′16.9″N, 120°44′16.5″E; 1050 m elevation); 1 female (TESRI CX018), 11 May 2018, Ying-Yuan Lo leg., Chongliao, Nantou County (23°53′59.2″N, 120°45′43.6″E, 170 m elevation)

Diagnosis. *Oxyopes striagatus* is similar to *O. macilentus* in body shape and coloration, as well as genital morphology. However, it can be distinguished from the latter species by the following characters: (1) The distal median protrusion of epigyne is columnar (acuminate in *O. macilentus*); (2) The base of male cymbium without lateral extension (with lateral extension in *O. macilentus*).

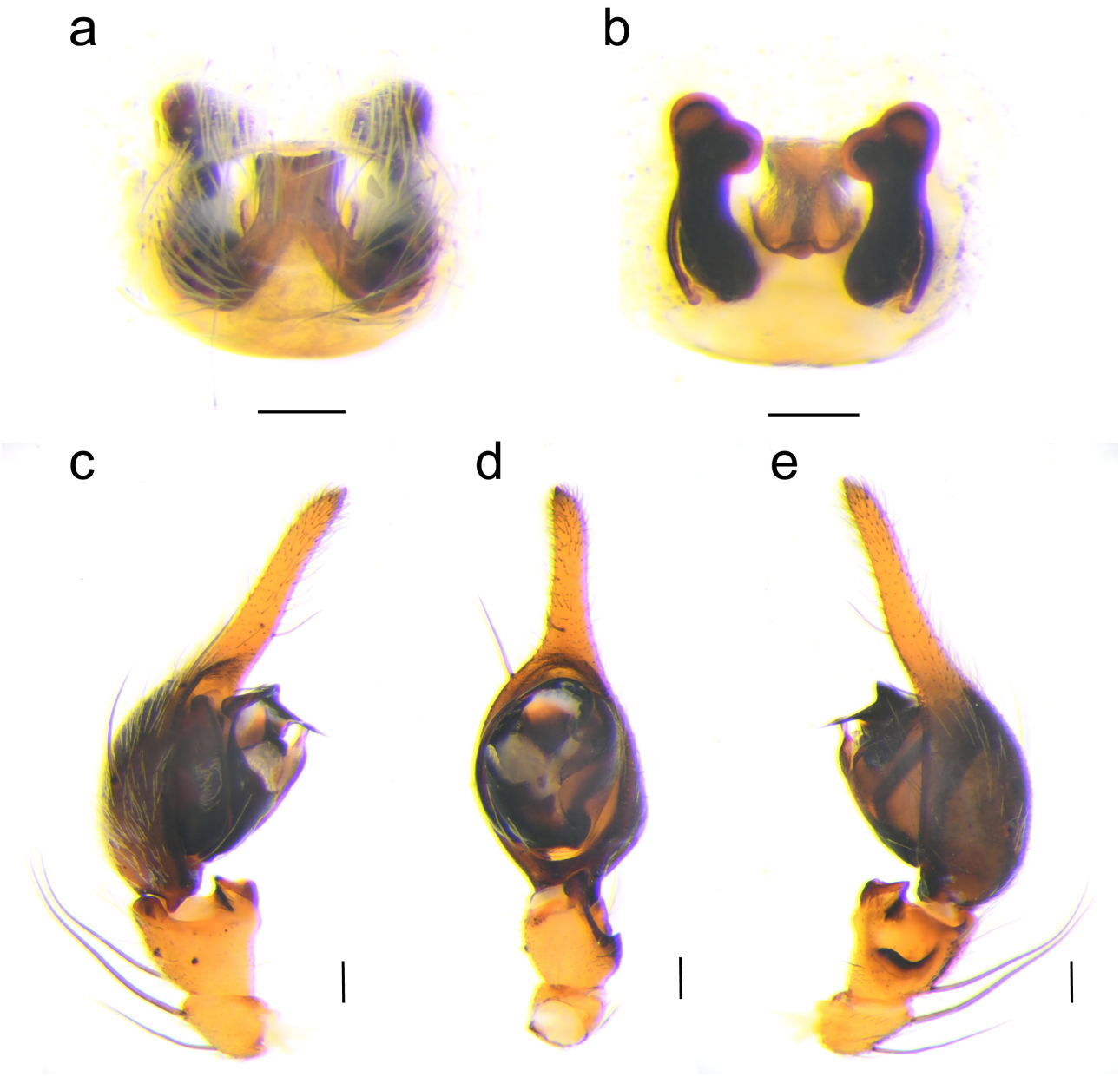

FIGURE 8. *Oxyopes striagatus* Song, 1991. (a–b) Epigyne (TESRI CX018): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar1758): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

Description. Female (TESRI CX018). Total length 8.0; carapace length 3.0, width 2.2; abdomen length 5.0, width 1.8. *Carapace* yellowish-green, pear shaped, with two olive-green central lines from PME extending to posterior margin, pair of same color but broader submarginal bands from PLE extending to posterior margin. Pale white bands between central and submarginal lines noticeable when alive (Fig. 12e) but obscure in alcohol. Fovea longitudinal. Clypeus high, with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.10, ALE 0.24, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.90, MOA-AW 0.38, MOA-PW 0.60; AME-I 0.18, PME-I 0.28, AML-I 0.08, PML-I 0.28; clypeus height 0.58. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endite and labium* longer than wide. *Sternum* yellowish with several setae. *Abdomen* fusiform, with reddish-brown cardiac mark extending to distal and approaching spinnerets, pair of conspicuous white bands on each side of cardiac mark (less obvious in ethanol). Abdomen laterally yellowish with two black stripes, white stripe between black stripes. In ventral view, broad dark longitudinal band extends from epigastric furrow to spinnerets. *Legs* clothed with many

conspicuous long spines with distinct black stripes on venter of femur I–III and dorsum of tibia I–III. Three claws. Pedipalps bear apical claw. Measurements of pedipalp and legs: pedipalp 3.6 (1.1, 0.5, 0.8, 1.2), leg I 14.5 (3.8, 1.0, 4.2, 4.0, 1.5), leg II 12.9 (3.5, 1.0, 3.7, 3.5, 1.2), leg III 10.6 (3.0, 0.9, 2.7, 3.1, 0.9), leg IV 12.8 (3.7, 0.9, 3.2, 3.9, 1.1). Leg formula: I > II ≒ IV > III. *Epigyne* sclerotized on posterior edge with columnar median projection. Pair of spermathecae visible though exoskeleton. Copulatory ducts thick, curved, arc-shaped, with rounded spermathecae on apical side. Fertilization ducts slender, elongate with hook-like apex.

Male (TESRI Ar1758). Body shape and coloration similar to those of female, but markings more variegated, abdomen thinner. Total length 7.3; carapace length 3.1, width 2.4; abdomen length 4.2, width 1.5. Eye diameters and inter-distances: AME 0.10, ALE 0.22, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.86, MOA-AW 0.34, MOA-PW 0.56; AME-I 0.14, PME-I 0.24, AML-I 0.08, PML-I 0.28; clypeus height 0.54. Measurements of pedipalp and legs: pedipalp 4.2 (1.2, 0.4, 0.5, 2.1), leg I 14.6 (3.8, 1.0, 4.0, 4.0, 1.8), leg II 13.1 (3.6, 0.9, 3.5, 3.7, 1.4), leg III 10.7 (3.1, 0.9, 2.6, 3.0, 1.1), leg IV 13.6 (4.0, 0.9, 3.6, 3.9, 1.2). Leg formula: I > II ≒ IV > III. *Palp* tibia with a slight retrolateral depression and two separate apophyses: ventral retrolateral tibial apophysis larger and broad while dorsal retrolateral tibial apophysis arc shaped. Conductor curved with slender apex. Embolus slender, distal part concealed by conductor. Median apophysis distally tapered, extending ventrally with apex of conductor.

Size Variation. Three female and four male specimens were measured to quantify the morphological variations. Values are mean ± SD of females (with the male in parentheses). Total length 9.0 ± 1.6 (7.0 ± 0.5); cephalothorax length 3.1 ± 0.4 (2.9 ± 0.3), width 2.3 ± 0.3 (2.3 ± 0.2); abdomen length 5.9 ± 1.2 (4.1 ± 0.2), width 2.3 ± 0.7 (1.6 ± 0.1). Diameters of AME 0.11 ± 0.01 (0.10 ± 0.02), ALE 0.23 ± 0.03 (0.22 ± 0.02), PME 0.19 ± 0.03 (0.17 ± 0.03), PLE 0.19 ± 0.03 (0.17 ± 0.03). MOA-L 0.91 ± 0.07 (0.81 ± 0.08), MOA-AW 0.37 ± 0.03 (0.33 ± 0.03), MOA-PW 0.60 ± 0.06 (0.54 ± 0.04); AME-I 0.18 ± 0.00 (0.13 ± 0.02), PME-I 0.28 ± 0.02 (0.24 ± 0.03), AML-I 0.09 ± 0.03 (0.07 ± 0.01), PML-I 0.29 ± 0.04 (0.26 ± 0.03). Clypeus height 0.62 ± 0.11 (0.52 ± 0.06). Pedipalp 3.2 ± 0.5 (3.9 ± 0.3), leg I 14.8 ± 2.1 (14.4 ± 0.4), leg II 13.3 ± 2.0 (12.6 ± 0.6), leg III 10.9 ± 1.8 (10.1 ± 0.5), leg IV 13.1 ± 1.8 (12.3 ± 1.1).

Distribution. China (Song 1991) and Taiwan (newly recorded).

Remark. Although we did not examine the type specimen, the original illustration and description are unequivocal to confirm that specimens from Taiwan belong to *O. striagatus*.

Oxyopes sushilae **Tikader, 1965**

Fig. 13

Oxyopes sushilae Tikader, 1965: 141–143, fig. 2 (holotype: 1 female, Savitribai Phule Pune University, Kaharashtra, ZSI, not examined). Hu *et al*. 1985: 28–31, figs 1–8; Song 1991: 175–177, fig. 7; Zhu & Zhang 2011: 337, fig. 244; Yin *et al*. 2012: 920, fig. 466; Lo & Lin 2016: 139, figs 1–7.

Material examined. All specimens were collected from Taiwan.

2 females (TESRI Ar0909–0910) and 2 males (TESRI Ar0907–0908), 10 Apr. 2014, Ying-Yuan Lo leg., Taomikeng, Nantou County (23°56′33.0″N, 120°56′01.2″E, 465 m elevation); 2 males (TESRI Ar0400/0526), 24 Apr. 2013, Ying-Yuan Lo leg., Shitoushan, Miaoli County (24°38′03.1″N, 121°01′02.4″E, 190 m elevation); 1 male (TESRI Ar0523), 18 Apr. 2013, Ying-Yuan Lo leg., Sanmin, Taoyuan City (24°50′16.9″N, 121°20′35.6″E, 335 m elevation); 2 females (TESRI Ar0519–0520) and 1 male and (TESRI Ar0518), 17 Apr. 2013, Ying-Yuan Lo leg., Datieliao Old Trail, Taoyuan City (24°51′06.8″N, 121°17′53.2″E, 190 m elevation); 1 male (TESRI Ar0887), 18 Jun. 2014, Ying-Yuan Lo leg., Shishan Forest Road, Kaohsiung City (23°05′05.5″N, 120°47′19.5″E, 1680 m elevation); 2 females (TESRI Ar0768–0769), 22 Apr. 2014, Ying-Yuan Lo lge., 2 females (TESRI Ar0982/1016), 02 Sep. 2014, Ying-Yuan Lo leg., Qipan Village, Yunlin County (23°40′49.9″N, 120°36′49.4″E; 140 m elevation); 1 female (TESRI YMS200), 09 Jun. 2018, Li-Jing Huang leg., Pamier Park, New Taipei City, Taiwan (25°07′20.4″N, 121°35′37.0″E; 350 m elevation)

Diagnosis, description and variation. For the details see Lo & Lin (2016).

Distribution. India, China (Tikader 1965; Hu *et al*. 1985), and Taiwan.

***Oxyopes taiwanensis* sp. nov.**
Figs 9–10, 13c–e

Material examined. All specimens from Taiwan.

Holotype. 1 male (TESRI Ar1313), 12–13 Apr. 2015, Ying-Yuan Lo leg., Orchid Island, Taitung County (22°04′38.8″N, 121°30′36.4″E; 150 m elevation).

Paratypes. 1 female (TESRI Ar0315) and 1 male (TESRI Ar0525), 26 Jun. 2013, Ying-Yuan Lo leg., Kenting, Pingtung County (21°56′58.2″N, 120°47′52.1″E; 20 m elevation); 2 females (TESRI Ar1314/1317), 12–13 Apr. 2015, Ying-Yuan Lo leg., Orchid Island, Taitung County (22°04′38.8″N, 121°30′36.4″E; 150 m elevation); 1 female (TESRI Ar1776), 13 May 2016, Hui-Ling Cheng leg., Duoliang Village, Taitung County (22°30′26.0″N, 120°57′22.3″E, 160 m elevation).

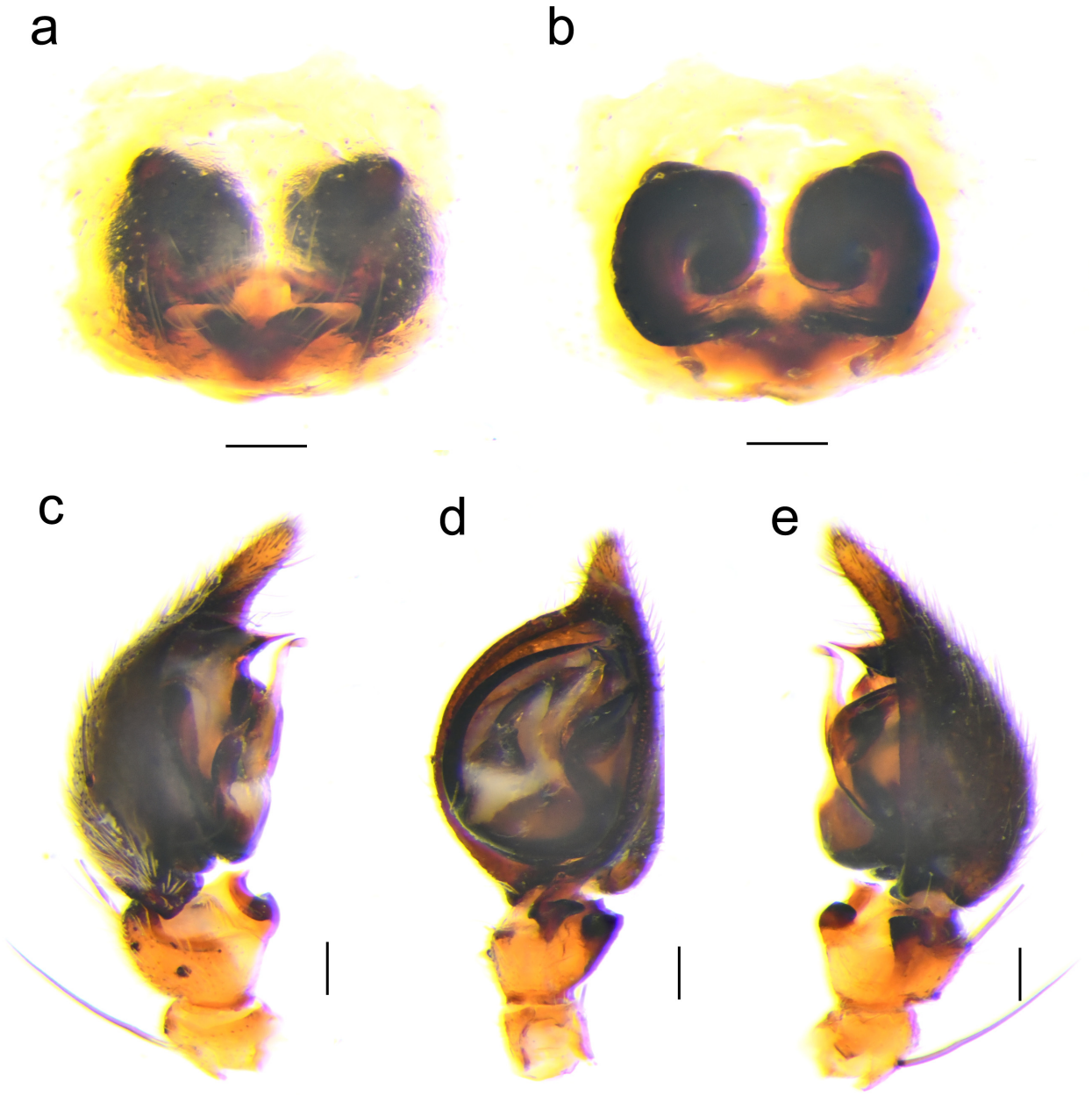

FIGURE 9. *Oxyopes taiwanensis* **sp. nov.** (a–b) Epigyne (TESRI Ar1776): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar1313): (c) prolateral; (d) ventral; (e) retrolateral. Scale bars: 0.2 mm.

Other material examined. 1 female (TESRI Ar1777), 13 May 2016, Hui-Ling Cheng leg., Duoliang Village, Taitung County (22°30′26.0″N, 120°57′22.3″E, 160 m elevation); 2 males (TESRI Ar0842–0843), 28 May 2014, Ying-Yuan Lo leg., Jinlun Forest Road, Taitung County (22°31′57.7″N, 120°56′33.0″E; 70 m elevation); 2 females (TESRI Ar0536–0537), 14 Jan. 2014, Ying-Yuan Lo leg., Shihba Luohanshan, Kaohsiung City (22°56′56.0″N, 120°38′29.6″E, 220 m elevation); 1 female (TESRI Ar2756) and 1 male (TESRI Ar2757), 27 Jun. 2018, Yi-Lun Lin leg., Orchid Island, Taitung County, Taiwan (22°01′44.7″N, 121°34′43.3″E; 18 m elevation)

Diagnosis. *Oxyopes taiwanensis* **sp. nov.** is similar to *O. sertatus* in the morphology of male palps and to *O. sertatoides* in the transverse twist of copulatory ducts of the epigyne. However, it can be recognized by the following characters: (1) the dorsal retrolateral tibial apophysis of male palps is incisor-shaped in ventral view (longitudinal and ridge-shaped in *O. sertatus*), and without a triangular black outgrowth (triangular outgrowth in *O. sertatoides*); (2) the female copulatory duct is curved more strongly than those of *O. sertatus* and *O. sertatoides*.

Etymology. The specific name '*taiwanensis*' refers to the location where the type specimen was collected.

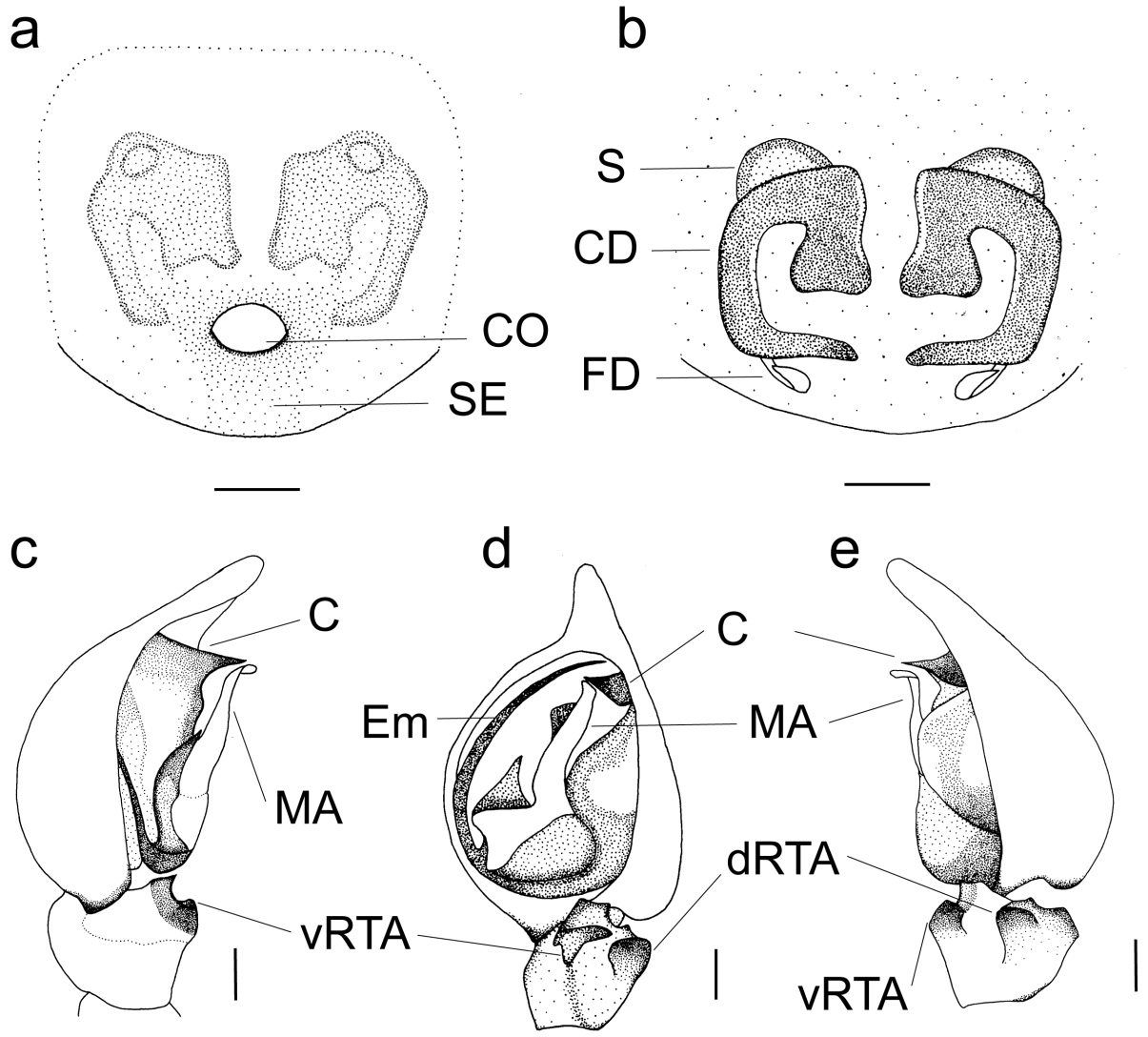

FIGURE 10. *Oxyopes taiwanensis* **sp. nov.** (a–b) Epigyne (TESRI Ar1776): (a) ventral; (b) dorsal. (c–e) Palp (TESRI Ar1313): (c) prolateral; (d) ventral; (e) retrolateral. **C**: conductor; **CD**: copulatory duct; **CO**: copulatory opening; **dRTA**: dorsal retrolateral tibial apophysis; **Em**: embolus; **MA**: median apophysis; **FD**: fertilization duct; **S**: spermatheca; **SE**: sclerotized edge; **vRTA**: ventral retrolateral tibial apophysis. Scale bars: 0.2 mm.

Description. Female (TESRI Ar1776, Paratype). Total length 7.5; carapace length 3.3, width 2.5; abdomen length 4.2, width 2.1. *Carapace* yellowish-green, pear shaped with pair of brown lines extending from PME to posterior margin, pair of larger dark patches on submargin. Fovea longitudinal. In dorsal view, eyes arranged in four rows, AER strongly recurved, PER strongly procurved. Clypeus high with two black stripes from AME margin to front of each chelicera. Eye diameters and inter-distances: AME 0.12, ALE 0.26, PME 0.22, PLE 0.22, eye sizes ALE > PME = PLE > AME; MOA-L 1.02, MOA-AW 0.42, MOA-PW 0.74; AME-I 0.20, PME-I 0.30, AML-I 0.08, PML-I 0.32; clypeus height 0.78. *Chelicerae* downward with two promarginal teeth, first larger than second, one retromarginal tooth. *Endites and labium* longer than wide. *Sternum* yellowish-green with several setae. *Abdomen* fusiform with ivory longitudinal central band. Cardiac mark ivory with brown margin. Lateral region dark with two slant, ivory stripes connecting with central band. In ventral view, broad dark longitudinal band extending from epigastric furrow to spinnerets. *Legs* clothed many conspicuous long spines and with black stripes on venter of femur. Three claws. Pedipalps bear apical claw. Measurements of pedipalp and legs: pedipalp 3.4 (1.1, 0.4, 0.7, 1.2), leg I 13.5 (3.7, 1.1, 3.5, 3.8, 1.4), leg II 12.7 (3.5, 1.1, 3.2, 3.6, 1.3), leg III 10.4 (2.9, 1.0, 2.4, 3.1, 1.0), leg IV 11.0 (3.0, 1.1, 2.4, 3.4, 1.0). Leg formula: I > II > IV > III. *Epigyne* with central depression. Posterior edge sclerotized, incrassate, V-shaped. Copulatory ducts thick and curved, with distal transversal twist. Spermathecae rounded. Fertilization ducts slender and elongate posteriorly with hook-like apex.

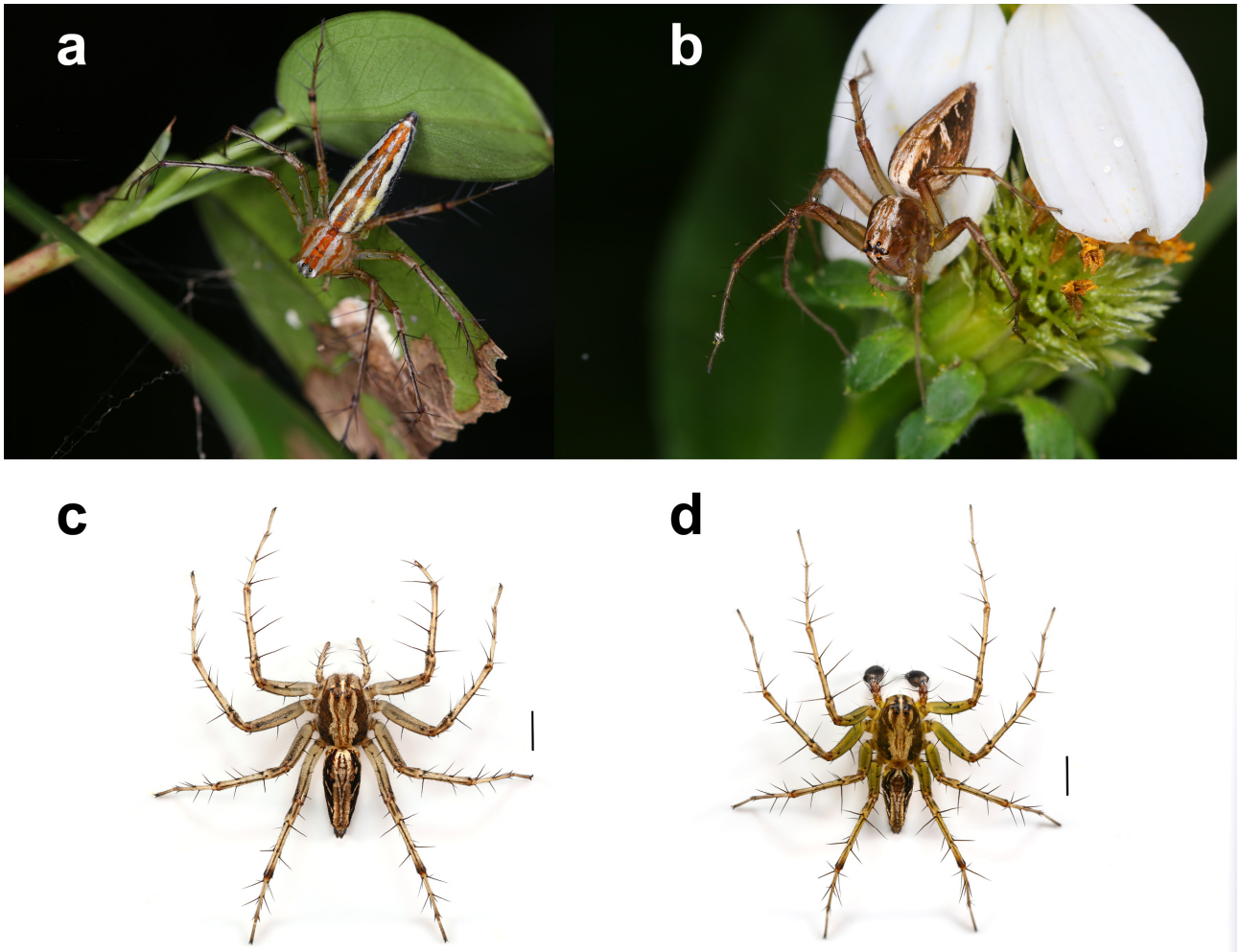

FIGURE 11. Habitus of *Oxyopes jujianicus* Song & Zhu, 1993 and *Oxyopes hasta* **sp. nov**. (a) *O. fujianicus*, female; (b) *O. hasta*, female; (c) *O. hasta*, female (TESRI Ar2824); (d) *O. hasta*, male (TESRI Ar2822). Scale bars (c–d): 2 mm.

Male (TESRI Ar1313, Holotype). Body shape and coloration pattern similar to those of female, but markings more variegated and abdomen thinner. Total length 5.8; carapace length 2.7, width 2.3; abdomen length 3.1, width 1.4. Eye diameters and inter-distances: AME 0.10, ALE 0.22, PME 0.18, PLE 0.18, eye sizes ALE > PME = PLE > AME; MOA-L 0.86, MOA-AW 0.38, MOA-PW 0.58; AME-I 0.18, PME-I 0.28, AML-I 0.06, PML-I 0.30; clyp-

eus height 0.60. Measurements of pedipalp and legs: pedipalp 3.3 (1.1, 0.3, 0.4, 1.5), leg I 11.5 (2.9, 0.9, 2.8, 3.3, 1.6), leg II 10.5 (2.7, 0.9, 2.5, 2.9, 1.5), leg III 8.8 (2.5, 0.8, 1.9, 2.6, 1.0), leg IV 10.2 (2.9, 0.8, 2.2, 3.2, 1.1). Leg formula: I > II > IV > III. *Palp* tibia with a retrolateral depression and two separate apophyses. Dorsal retrolateral tibial apophysis incisor-shaped, while ventral retrolateral tibial apophysis protrudes ventrally with triangular apex pointing retrolaterally. In lateral view, ventral retrolateral tibial apophysis crescent-shaped. Cymbium with basal extension on retrolateral side. Conductor broad with sharp apex. Embolus slender, encompassing prolateral side of genital bulb. Median apophysis white, laminar.

Size Variation. Five female and three male specimens were measured to quantify the morphological variation. Values are mean ± SD of males (with the female in parentheses). Total length 8.2 ± 1.1 (6.4 ± 1.0); cephalothorax length 3.4 ± 0.3 (3.0 ± 0.4), width 2.6 ± 0.2 (2.4 ± 0.2); abdomen length 4.8 ± 1.0 (3.5 ± 0.6), width 2.5 ± 0.7 (1.6 ± 0.3). Diameters of AME 0.11 ± 0.02 (0.11 ± 0.01), ALE 0.24 ± 0.03 (0.24 ± 0.03), PME 0.21 ± 0.03 (0.20 ± 0.03), PLE 0.21 ± 0.03 (0.20 ± 0.03). MOA-L 1.02 ± 0.06 (0.91 ± 0.13), MOA-AW 0.44 ± 0.03 (0.39 ± 0.04), MOA-PW 0.73 ± 0.03 (0.64 ± 0.10); AME-I 0.22 ± 0.03 (0.17 ± 0.03), PME-I 0.32 ± 0.04 (0.28 ± 0.04), AML-I 0.08 ± 0.02 (0.07 ± 0.01), PML-I 0.36 ± 0.03 (0.31 ± 0.03). Clypeus height 0.77 ± 0.05 (0.62 ± 0.07). Pedipalp 3.5 ± 0.2 (3.6 ± 0.4), leg I 12.9 ± 0.8 (12.7 ± 2.1), leg II 12.0 ± 0.7 (11.5 ± 2.0), leg III 9.9 ± 0.5 (9.5 ± 1.5), leg IV 11.6 ± 0.7 (10.9 ± 1.6).

Distribution. Endemic to Taiwan.

Remark. The epigyne of *Oxyopes taiwanensis* is very similar to the description and illustration of *O. sertatoides* by Xie & Kim (1996). The copulatory ducts of both species have a transverse twist, but the curvature on the middle part is more pronounced in *O. taiwanensis* than in *O. sertatoides*. Although the specimens of *O. sertatoides* described by Xie & Kim (1996) were unavailable to us for comparison, the morphology of the retrolateral tibial apophysis of *O. taiwanensis* is different from their illustration and description of *O. sertatoides* (with a triangular black outgrowth, see Xie & Kim 1996). Therefore, these two closely related species can be subjectively distinguished.

Like *O. sertatus* and *O. hasta*, *O. taiwanensis* mainly inhabits relatively more open habitats, such as grasslands and bush fallows. However, *O. taiwanensis* is rare; it is only distributed in a few localities in southern and eastern Taiwan, including offshore on Orchid Island.

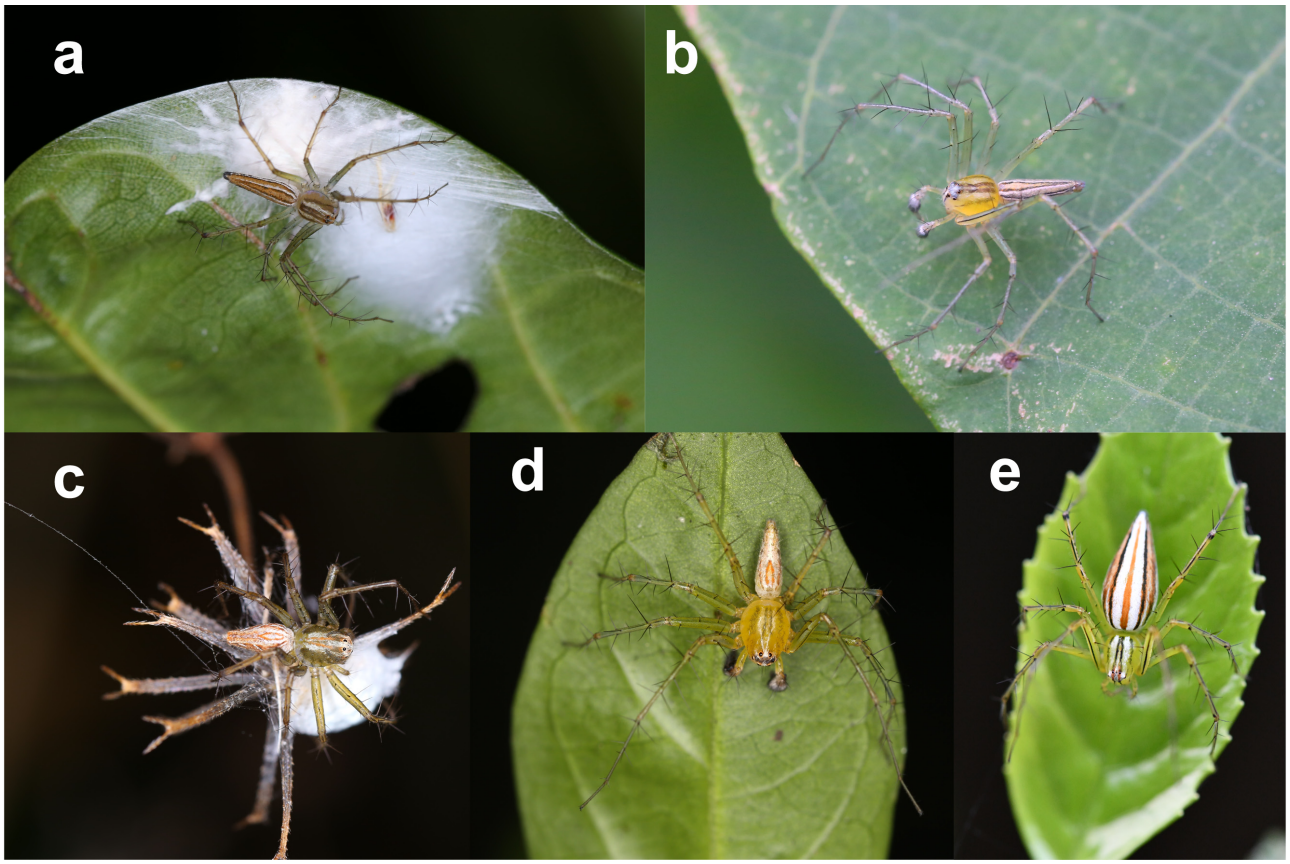

FIGURE 12. Habitus of *Oxyopes macilentus* L. Koch, 1878, *O sertatus* L. Koch, 1878, and *O. striagatus* Song, 1991. (a) *O. macilentus*, female; (b) *O. macilentus*, male; (c) *O. sertatus*, female; (d) *O. sertatus*, male; and (e) *O. striagatus*, female.

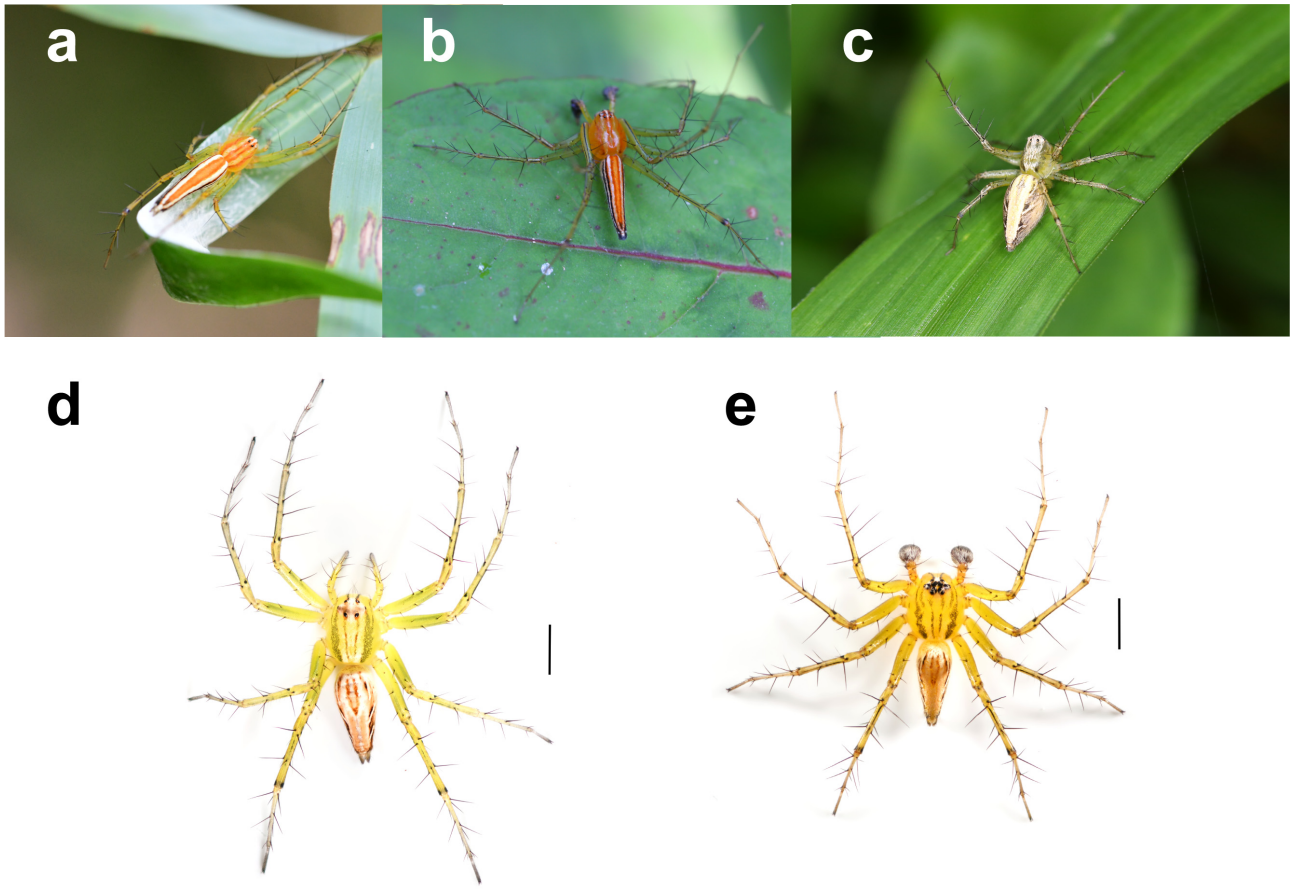

FIGURE 13. Habitus of *Oxyopes sushilae* Tikader, 1965 and *O. taiwanensis* **sp. nov**. (a) *O. sushilae*, female; (b) *O. sushilae*, male; (c) *O. taiwanensis*, female; (d) *O. taiwanensis*, female (TESRI Ar2756); (e) *O. taiwanensis*, male (TESRI Ar2757). Scale bars (d–e): 2 mm.

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