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Taxonomic revision of *Elatostema* J. R. Forst. & G. Forst. (Urticaceae) in Taiwan

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ABSTRACT: The genus *Elatostema* (Urticaceae) in Taiwan is taxonomically revised based on morphological characters, molecular phylogeny and geographic distribution. *Elatostema acuteserratum* is not only found in Lanyu, but also in southern and eastern of Taiwan. *Elatostema herbaceifolium* is treated as a synonym of *E. cyrtandrifolium* and we also confirm the existence of its male inflorescence in Taiwan. *Elatostema yonakuniense* in Japan is treated as a synonym of *E. microcephalanthum* that is not an endemic species in Taiwan and Japan. *Elatostema multicanaliculatum* is treated as a synonym of *E. oblongifolium* and *E. platyphylloides* as a synonym of *E. platyphyllum* and these two taxa are no longer endemic species in Taiwan. In summary, there are a total of sixteen species in Taiwan, including one hybrid species.

KEY WORDS: *Elatostema*, endemic species, Taiwan, taxonomic revision.

INTRODUCTION

The genus *Elatostema* J. R. Forst. & G. Forst. (Urticaceae) comprises about 500 species (Wang, 2012) and the majority of which are widely distributed throughout from tropical to subtropical area of Africa, Asia and Oceania. Many species of this genus are herbs, some small shrubs or subshrubs that grow in moist forest understory, ravine and/or cave. Because of the homology of morphological characters, numerous species and wide distribution, the delimitation of inter-(with *Pellionia* and *Procris*) and infra-generic relationships (five sections: *Androsyce*, *Elatostema*, *Laevisperma*, *Pellionoides*, *Weddellia*, and/or four subgenera: *Elatostema*, *Elatostematoides*, *Pellionia*, and *Weddellia*) (Schröter and Winkler, 1935; Wang, 1980) concerning with *Elatostema* are still uncertain.

Augustine Henry (1896) first documented the existence of *Elatostema* species in Taiwan, based on his collections from southern Taiwan (three *E.* spp., *Henry 53* & *202*, *154*, *1617*). Subsequently, five species were recognized in the A List of Plants of Formosa by Kawakami (1910), including *E. ficoides* Wedd., *E. lineolatum* Forst. var. *major* Thw., *E. minutum* Hayata, *E. platyphyllum* Wedd., *E. sessile* Forst. var. *cuspidatum* Wedd. In Icons Plantarum Formosanarum, Hayata (1916) described four species: *E. herbaceifolium* Hayata, *E. lineolatum* Wright var. *major major* Thw., *E. microcephalanthum* Hayata and *E. minutum*. Subsequently Yamazaki (1972), in his studies of the flora of Ryukyu and Formosa, suggested that Hayata (1911)'s *Pellionia trilobulata* Hayata, a subalpine plant in Taiwan, should be treated under *Elatostema* as *E. trilobulatum* (Hayata) Yamazaki. In the Flora of Taiwan 1st edition (Liu and Huang, 1976), six species of *Elatostema* were recognized, including *E. edule* Rob., *E. herbaceifolium*, *E. lineolatum* var. *major*, *E. minutum*, *E. platyphyllum* and *E. sessile* var. *cuspidatum.* Later on in the Flora of China, Wang (1980) concluded that there were eight species of *Elatostema* in Taiwan, i.e. *E. cuspidatum* Wight, *E. edule*, *E. herbaceifolium*, *E. lineolatum* Wight var. *majus* Thw., *E. microcephalanthum*, *E. obtusum* var. *trilobulatum* (Hayata) Wang, *E. parvum* (Bl.) Miq. and *E. platyphyllum*. In Wang's study, *E. trilobulatum* was treated as a synonym of *E. obtusum* var. *trilobulatum* due to the similar morphological characters of stem, leaf size, teeth number with *E. obtusum*, even though the leaf shape showed variations among the individuals (Wang, 1980).

The most recent revisionary work of *Elatostema* in Taiwan was made by Yang *et al.* (1995), in which a total of 15 species were proposed. Yang *et al.* (1995) agreed the existence of *E. edule*, *E. herbaceifolium*, *E. lineolatum* Wight var. *majus* Wedd., *E. microcephalanthum*, *E. parvum* and *E. trilobulatum*, and also recognized nine new species (*E. acuteserratum* Shih & Yang, *E. hirtellipedunculatum* Shih & Yang, *E. hypoglaucum* Shih & Yang, *E. multicanaliculatum* Shih & Yang, *E. platyphylloides* Shih & Yang, *E. rivulare* Shih & Yang, *E. strigillosum* Shih & Yang, *E. subcoriaceum* Shih & Yang and *E. villosum* Shih & Yang). Eleven of them are endemic to Taiwan, and *E. acuteserratum* was only found in Lanyu (Shih *et al.*, 1995; Yang *et al.*, 1995). Among these species, Shih *et al.* (1995) indicated that *E. platyphylloides* was misidentified as *E. platyphyllum* in previous studies, while the former could be distinguished from the later

by having hirsute hairs on abaxial sides of stipules and 1–2 inflorescences at a node. In addition, *E. trilobulatum* had two-rowed hairs on the stem and 5–6 flowers on one male inflorescence, and was different from *E. obtusum* that had hairs throughout the stems and 1–3 male flowers on a single inflorescence (Yang *et al.*, 1995). Later, Lin (2003) and Chen (2003) suggested that *E. herbaceifolium* should be treated as a synonym of *E. cyrtandrifolium* (Zoll. & Moritzi) Miq, but no description and evidence were provided. Recently, our lab reported a case in Taiwan (Tseng & Hu 2014) for the first natural hybrid of *Elatostema*, which is derived from *E. lineolatum* var. *majus* as maternity and *E. platyphylloides* as paternity. In our field investigations, we found the absence of male flowers in *E. multicanaliculatum* and *E. rivulare*, but both species were able to produce seeds and also supposed to have the ability for apomictic reproduction (Tseng and Hu, unpublished).

In this paper, a short revision of *Elatostema* in Taiwan was carried out based on field observation, careful examination of specimens and molecular phylogeny. Taxonomic description and distribution are provided including several nomenclatural modifications and some newly distributed records.

MATERIALS AND METHODS

Taxon sampling

Our sampling strategy aimed to sample all *Elatostema* species of Taiwan and also increase the sampling number of uncertain species from nearby regions. Taxon samplings covered the field populations from Taiwan, China, Japan and Indonesia, as well as specimens from A, K, IBK and TAIF. Materials for molecular analysis were listed in Appendix 1. The vouchers used in this study are deposited at TAI.

Genomic DNA extraction & sequencing

Total genomic DNAs were isolated from fresh or dried materials using modified CTAB protocol by Li *et al.* (2005). The *rpl32-trnL* sequences of the selected taxa were determined by PCR and the subsequent sequencing of the PCR products. For each PCR, amplification was performed in a total volume of 50 μl, including 5 μl 10× PCR buffer, 1 μl 10mM dNTP (2.5 mM each), 1 μl of each specific primer (10 μM each), 1 μl template, and 0.2 μl MDBio Taq DNA Polymerase (MDBio Inc., Taipei, Taiwan). The primers $trnL^{(UAG)}$ and rpL32-F were used in most cases for both PCR amplification and sequencing (followed Shaw *et al.*, 2007). For some samples that did not work with these two primers, especially samples from dried specimens, additional primers (trnL-F1: TAT TGG GCA GCG TTG AAA GC; trnL-F2: GAG TTG CTT TAA TTC GMA AAG; trn-F-Pel: ATG GGG AAA ATA AGA ATC CC; rpl32-R1-Pel: GGC GTA TTC TTC CTA TAA CC) were designed to optimize PCR amplification and sequencing. The PCR reactions were 94°C for 5 min, 35 cycles of 94°C for 30 s, 60°C for 30 s and 72°C for 45 s, and final extension in 72°C for 5 min. PCR products were purified using a QIAquick PCR purification kit (QIAGEN, Hilden, Germany). Nucleotide sequences were determined using an automated sequencer ABI PRISM 337 (Applied Biosystems, Foster City, California, USA), and assembled by Sequencher 4.0 (Gene Codes Corp., Ann Arbor, MI, USA).

Sequence alignment and phylogenetic analysis

The *rpl32-trnL* sequence data were generated for 38 accessions, representing 29 taxa (28 ingroup, 1 outgroup). Alignment was conducted using ClustalX 1.83 (Thompson *et al.*, 1997) and verified in MacClade 4.06 (Maddison and Maddison, 2000). Phylogenetic analyses for the aligned matrix were performed by maximum parsimony (MP), Bayesian inference (BI) and maximum likelihood (ML) methods. MP analyses were carried out using PAUP* 4.0b10 (Swofford, 2002). Heuristic searches were conducted with 1,000 random addition replicates followed by tree bisection -reconnection branch swapping with steepest-descent option in effect. Branch supports were assessed by 1,000 bootstrap replicates with the sample settings as for heuristic searches. The BI analyses were done using MRBAYES 3.0b4 (Huelsenbeck and Ronquist, 2001). The BI analyses were run with four chains of Markov chain Monte Carlo (MCMC) simulation for 1,500,000 generations and sampled one tree per 500 generations. The first 500 trees of sampled trees were discarded before the node probability was calculated. The ML analyses with 1,000 bootstrap resampling were conducted using RAxML-HPC2 v8.0.24 (Stamatakis *et al.*, 2008) on the CIPRES Portals (http://www.phylo.org/index.php/portal/) (Miller *et al.*, 2010), under Gamma model of rate heterogeneity.

RESULTS & DISCUSSION

Individual sequence of *rpl32-trnL* showed length variation from 709 to 1,087 base pairs. This resulted in a total aligned length of 1,373 sites, of which 137 were parsimony informative. Phylogenetic analyses from three different methods revealed the consistent topologies. *Pellionia* taxa (including *P. minima*, *P. radicans* and *P. scabra*) formed a monophyletic group

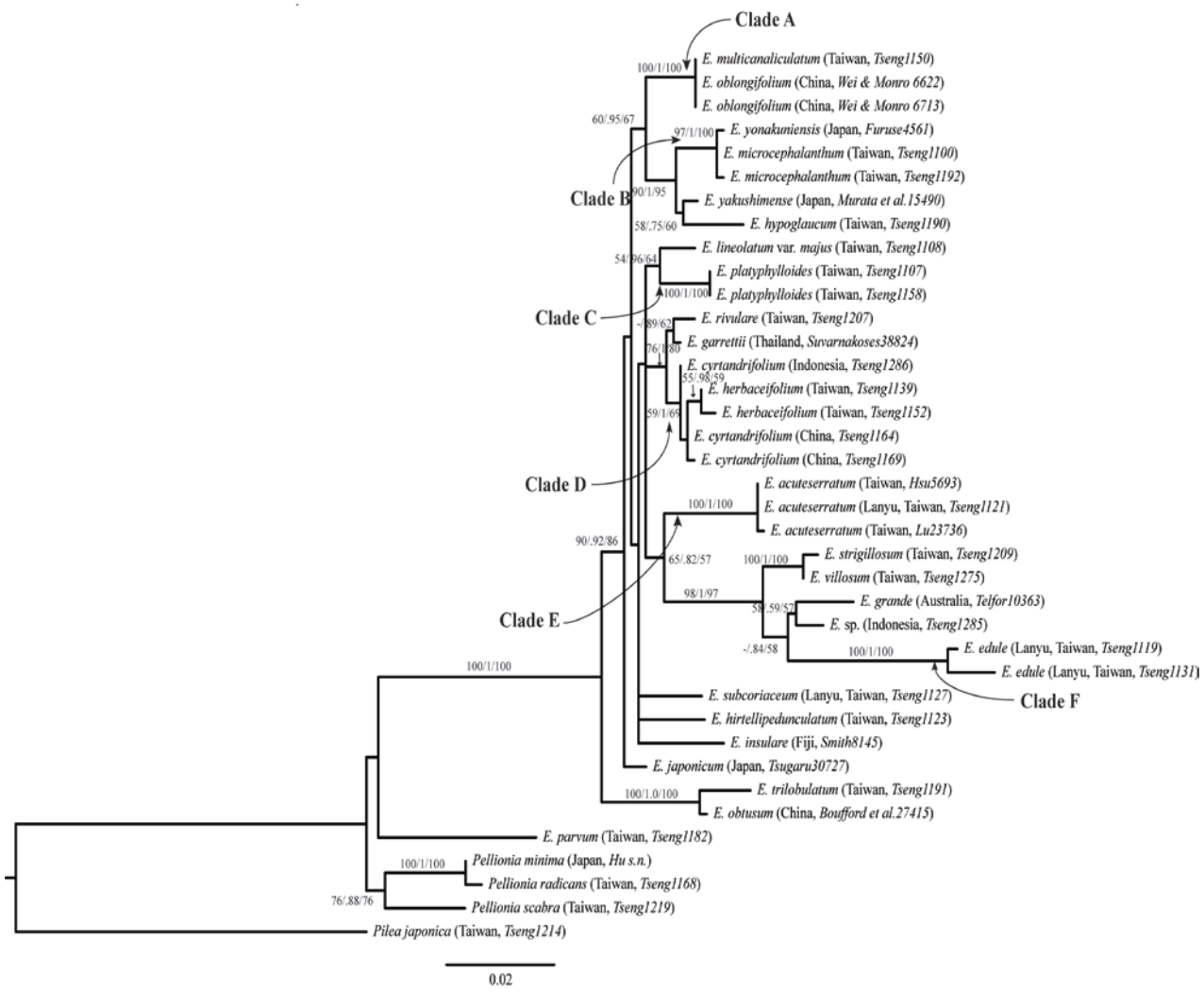

Fig. 1. Phylogenetic tree produced by maximum likelihood based on the *rpl32-trnL* intergenic spacer, with >50% clade supports (parsimony bootstrap/posterior probability/likelihood bootstrap) shown at each node. Arrows pointed to clades are discussed in the text. The location and collection number of each taxa are given following species name.

and also occupied the basal position of all studied samples (Fig. 1). The position of *E. parvum* is still uncertain among the analyses, which might be the sister group with *Pellionia* clade (MP tree, 65% support) or have unresolved relationship between *Pellionia* clade and other Elatostema taxa (BI and ML trees). Other *Elatostema* taxa, except for *E. parvum*, form a monophyletic clade with strong supports (MP: 100, BI: 1.0, ML: 100).

Elatostema acuteserratum was previously regarded as an endemic species in Lanyu (Shih *et al.* 1995; Yang *et al.* 1995), but was also found in southern and eastern of Taiwan based on recent herbarium collections at TAIF (*T. C. Hsu 5693*, *P. F. Lu 23736*). The phylogenetic analysis also showed that samples of *E. acuteserratum* from Lanyu and Taiwan formed a monophyletic group and also shared the highly similar sequences (only 2 variant sites out of 824 bps) (Fig. 1, Clade E), further confirming that these samples are the same species.

Elatostema herbaceifolium is widely distributed at low to medium altitudes, mainly growing along ravines or in the understory of shady and moist forests in Taiwan. The name of *E. herbaceifolium* was proposed by Hayata (1916) and this name was adopted by Wang (1980), Yang *et al.* (1995) and Flora of Taiwan Volume 2 (2nd ed.) (Yang *et al.*, 1996). In the publications of Lin (2003) and Chen (2003), this name was treated as a synonym as *E. cyrtandrifolium.* In our study, materials of specimens from Taiwan (Fig. 2C, 2D), China (Fig. 2B) and our own collections from Java (type locality; *Y. H. Tseng 1280*, *1286*; Fig. 2A) showed the identical morphology. Meanwhile in the phylogenetic tree, samples from Taiwan (*E. herbaceifolium*) formed a clade with those from China (*E. cyrtandrifolium*), and

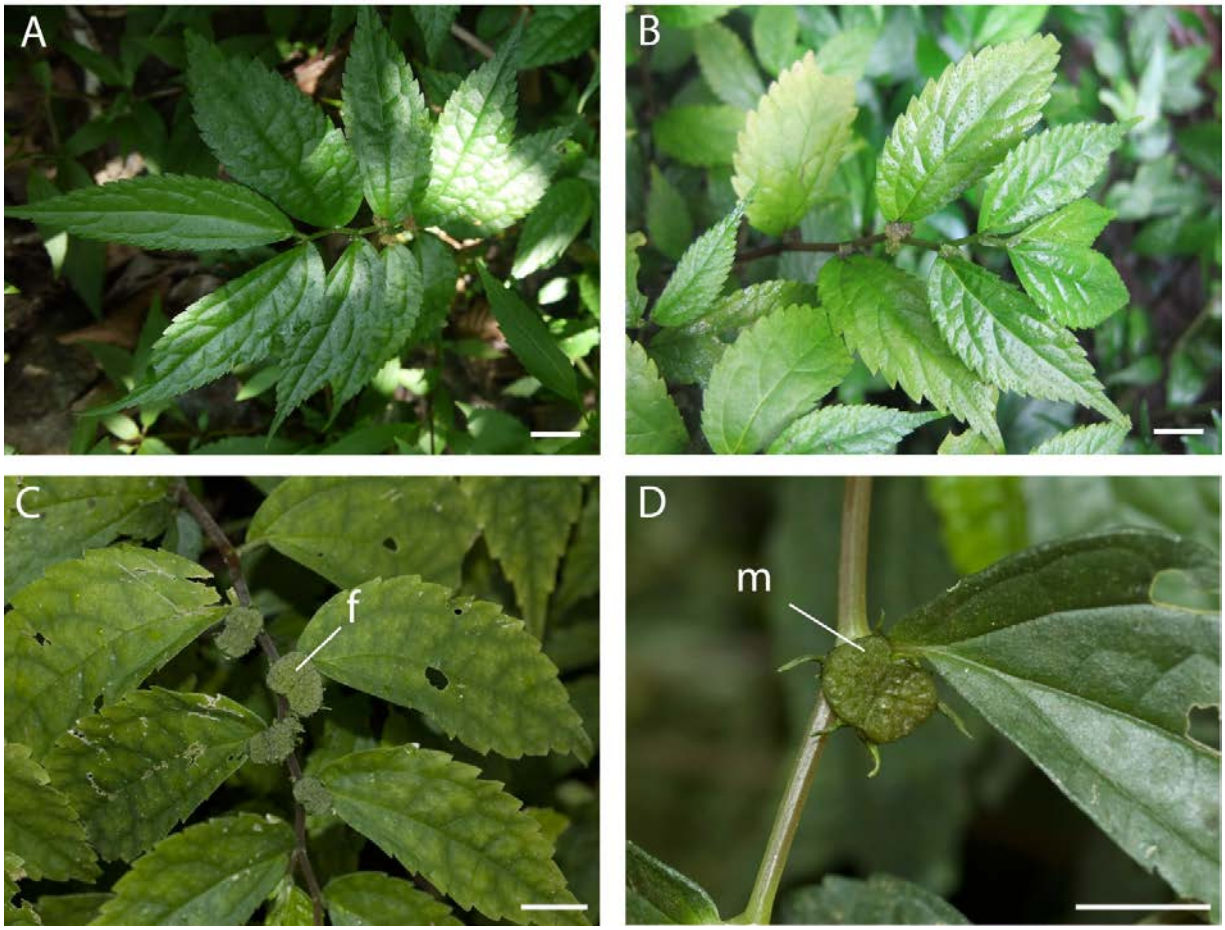

Fig. 2. Photographs of *Elatostema cyrtandrifolium*. A: plant in the type locality of Indonesia. B: plant in China. C, D: plant in Taiwan. f: female inflorescence; m: male inflorescence (Scale bar = 1 cm).

this clade is sister to the sample from Indonesia (*E. cyrtandrifolium*) (Fig. 1, Clade D). Therefore, we agree with the treatments of Lin (2003) and Chen (2003) due to the morphological and molecular evidences. In addition, Hayata (1916) only stated the female flowers, and the male flowers of this species had not yet been found in Taiwan (Yang *et al.*, 1995). During our recent survey in Nanshan, Ilan County, we found few male inflorescences for the first time (*Y. H. Tseng* 1274; Fig. 2D). Therefore, the description of male flowers is supplemented in this study.

In Taiwan, *E. microcephalanthum* is commonly distributed at medium altitude throughout the island and usually grows in the moist understory of forests. Hatusima (1963) described *E. yonakuniensis* from Yonakuni Island of Japan. He also indicated that this species resembled to *E. microcephalanthum*, but differed from its nearly glabrous oblong-obovate leaves. *Elatostema yonakuniensis* was also regarded as an endemic species in Japan (Tateishi, 1993), but we found that there is no difference between these two taxa based on the leaf shape, male flowers and hairs after a careful examination. Moreover, the key characters to distinguish between *E. yonakuniensis* and *E. microcephalanthum* as mentioned by Hatusima (1963) are within the range of variation of *E. microcephalanthum*. Compared with *E. yonakuniensis*, the leaf shape of *E. microcephalanthum* is asymmetrically obovate, ovate to obovate-lanceolate, or oblong-obovate and the adaxial sides are sparely to slightly hirsute or slightly dense hairy. In addition, *E. microcephalanthum* and *E. yonakuniensis* are grouped with high supports (MP: 97, BI: 1, ML: 100) into a clade in the phylogenetic analysis (Fig. 1, Clade B). One of samples of *E. yonakuniensis* examined (*Furuse 4205*, provided by K) was collected from the type locality. Therefore, we concluded that *E. yonakuniensis* should be treated as a synonym of *E. microcephalanthum* and this species is found both in Taiwan and Japan, thus not an endemic species to any place of both regions.

Elatostema multicanaliculatum was published by Yang *et al.* (1995) and was also suggested as an endemic species in Taiwan. Yang *et al.* (1995)

Fig. 3. Photographs of *Elatostema oblongifolium*. Plant (A: Taiwan; C: China) and stem (B: Taiwan; D: China) (Scale bar = 1 cm).

indicated that *E. multicanaliculatum* was only found at medium altitude around Mt. Lala (Taoyuan Co.), but later collections extended the distribution to Miaoli, Chiayi and Nantou Counties, where it mostly grows on moist understory near ravines. Following the IUCN red list criteria (IUCN, 2001), this species was categorized into critically endangered (Wang *et al.*, 2012). During a field trip to China in 2012, we collected samples of *E. oblongifolium*, a species published by Wang (1980), from Guizhou and Guangxi Provinces. In the morphological examination, *E. multicanaliculatum* and *E. oblongifolium* showed a high similarity on longitudinal canals on stem, leaf shape, venation, and female flowers (Fig. 3). The phylogenetic analyses also resulted in a strongly supported clade (MP: 100, BI: 1, ML: 100) composed of one population of *E. multicanaliculatum* in Taiwan and two populations of *E. oblongifolium* from China (Fig. 1, Clade A). Based on the morphological and molecular phylogenetic analyses, we concluded that *E. multicanaliculatum* should be treated as a synonym of *E. oblongifolium*, thus this species was no longer endemic to Taiwan. Nonetheless, the male flowers of this species still have never been seen in Taiwan.

Shih *et al.* (1995) indicated that *E. platyphylloides* resembles *E. platyphyllum*, but differed by having hirsute hairs on abaxial sides of stipules and 1–2 inflorescences at a node. The original description of *E. platyphyllum* (Weddell, 1856) stated that the stipule is glabrous and no description about the number of

inflorescences at a node. But after examining on type specimens and other collections of *E. platyphylloides* and *E. platyphyllum* from herbaria, we found that inflorescences in these two species are usually solitary or in pairs, rarely 3 at node, and the abaxial surfaces of stipules are glabrous, slightly hirsute at apex or hirsute. Therefore, *E. platyphylloides* is the synonym of *E. platyphyllum*, not an endemic species in Taiwan, and the original description of *E. platyphyllum* should be corrected.

Elatostema edule had been misidentified as *E. platyphyllum* for a long time (Chen *et al.*, 2003). *Elatostema edule* is glabrous, having flesh leaves and light green and very succulent stems, releasing scent after the stem is broken, with entire tips at apex of leaves. In contrast, *E. platyphyllum* is glabrous to pubescent, with chartaceous leaves and dark green or brown-green stem and a woody stem base, without scent, with serrate tips at apex of leaves. Moreover, *E. platyphyllum* is distributed in India, Bhutan, Nepal, China, Taiwan, Japan and Philippines, but *E. edule* is confined in Taiwan and the Philippines. The results of phylogenetic analyses also supported that *E. platyphyllum* and *E. edule* were two distinctive species because they were classified into different clades (Fig.1, Clade C and Clade F).

Taxonomic treatment

Among the 16 species of *Elatostema* in Taiwan, we found that five of them needed to be revised. The five *Elatostema* taxa treated in this study are described below.

Elatostema acuteserratum B. L. Shih & Yuen P. Yang, Bot. Bull. Acad. Sin. 36: 260. 1995; Chen *et al.*, Fl. China 5: 147. 2003. Type: —TAIWAN. Taitung Co.: Lanyu, Hontaochi, 17 Sep 1994, *B. L. Shih 3187* (isotype: HAST!, TAI!, TAIF!).

銳齒樓梯草 (cf. Yang *et al.*, 1995)

Perennial monoecious or dioecious herbs. Stems erect or ascending, branched or rarely simple, up to 70 cm high, 0.5–1 cm across, green, glabrous. Leaves alternate, sessile to short-petiolate; lamina 11–18 cm long, 3.5–5.5 cm wide, asymmetrically narrowly elliptic to elliptic, membranous to thick chartaceous, pinnately nerved, lateral veins 5–8 pairs; the upper surface green, sparely strigose, with dense cystoliths, fusiform; the lower surface light green, puberulent along veins; apex acuminate to caudate; base asymmetric, acroscopic half cuneate, basiscopic half broadly cuneate; margin sharply serrate to dentate; petioles semi-terete; stipules persistent, glabrous, 3–5 mm long, 0.5–1 mm wide, narrowly triangular, acuminate at apex, 1-veined. Inflorescences unisexual. Staminate inflorescences 8–18 cm in diameter, discoid, greenish, slightly puberulous; peduncle 1–2 mm; receptacle 3.4–5.5 mm, broadly oblong to oblong; bracts 4.5–5 mm long, broadly triangular; bracteoles numerous, 2–3 mm long, narrowly oblong, cymbiform, membranous, semihyaline, apex mucronate, margin entire, glabrous. Pistillate inflorescences sessile to subsessile, 3–7 mm in diameter, ellipsoidal-discoid, white-green, hirsute outside; receptacle 3–4 × 1.5–2 mm, broadly ovate to ovate; bracts 1–1.5 mm long, connate, the basal two with a subulate horn-like projection; bracteoles numerous, 1–2 × 0.1–0.2 mm, linear-lanceolate, membranous, semihyaline, ciliate. Staminate flowers subtended by bracteoles; pedicel terete, 1–2.5 mm long, glabrous; sepals 5, 1–2 mm long, 0.5–1 mm wide, narrowly triangular, ciliolate at upper and margin; stamens 5, inflexed. Pistillate flowers subtended by bracteoles; staminodes 4; stigma penicillate; ovary 0.3–0.4 mm long, 0.1–0.15 mm wide, glabrous, straight, ellipisoidal. Achenes ovoid, 0.6–0.8 mm long, 0.2–0.3mm wide, 12-ribbed.

Specimen examined: **TAIWAN**: Taitung Co.: Lanyu, 19 Jul 2009, *Y. H. Tseng 1121* (TAI), 20 Jul 2009, *Y. H. Tseng 1124, 1126* (TAI), 7 Apr 2002, *T. Y. A. Yang et al. 14678* (TNM), 5 Apr 2004, *T. Y. A. Yang et al. 16270* (TNM), 27 Mar 2005, *T. Y. A. Yang et al. 17278* (TNM), 27 Jun 2005, *T. Y. A. Yang et al. 17577* (TNM), 5 Apr 2007, *T. Y. A. Yang et al. 19013* (TNM), 11 May 1999, *J. S. Wu 1618* (TNM), 31 Mar 1996, *S. Y. Lu 25030* (TAIF), 24 Apr 2011, *M. J. Jung 5438* (TAIF), 29 Jan 2010, *M. J. Jung 4772* (TAIF); Aopanling, 26 Jan 2010, *M. J. Jung 4746* (TAIF). Pingtung Co.: Shawuchun stream, 11 May 2012, *T. C. Hsu 5693* (TAIF); Mt. Laofo, 29 Apr 2012, *P. F. Lu 23736* (TAIF).

Elatostema cyrtandrifolium (Zoll. & Moritzi) Miq., Pl. Jungh. 1: 21. 1851; Backer & Bakhuizen, Fl. Java 2: 44. 1965.

台灣樓梯草 (cf. Yang *et al.*, 1995)

Procris cyrtandrifolia Zoll. & Moritzi, Syst. Verz. 74. 1846.
Elatostema herbaceifolium Hayata, Icon. Pl. Formosan. 6: 57. 1916. Type: —TAIWAN. *Hayata s.n.* (holotype: TAIF!).

Perennial monoecious herbs. Stems erect or ascending, branched or rarely simple, up to 70 cm high, ca. 0.5 cm across, brownish-red, glabrous to densely pubescent. Leaves alternate; lamina 5–15 cm long, 2.5–4.5 cm wide, asymmetrically narrowly elliptic to elliptic, membranous to chartaceous, pinnately nerved, lateral veins 4–6 pairs; the upper surface green, sparely strigose, with dense cystoliths, 0.2–0.25 mm long, fusiform; the lower surface pale-green, puberulent along veins; apex acuminate, entire; base asymmetric, acroscopic half cuneate, basiscopic half acute to rounded; margin sharply serrate, teeth 6–10 on acroscopic margin, 8–14 on basiscopic margin; petioles 1–5 mm long; stipules 2, opposite, caducous, 3–5 mm long, 0.5–1 mm wide, narrowly lanceolate-cymbiform. Inflorescences unisexual. Staminate inflorescences 6–13 mm in diameter, with two ellipsoidal parts, greenish;

peduncle 3–6 mm; receptacle 4–12 in diameter, broadly oblong to oblong; bracts 1.5–2.5 mm long, apex with a subulate horn-like projection; bracteoles numerous, 0.4–1.3 mm long, 0.3–0.5 mm wide, narrowly oblong, cymbiform, membranous, semihyaline, ciliate. Pistillate inflorescences sessile to subsessile, 1–1.5 cm in diameter, ellipsoidal; receptacle 3–10 mm long, 0.5–2.5 mm wide, oblong to ovate, slightly puberulent; bracts apex with a subulate horn-like projection; bracteoles numerous, 0.5–1.3 mm long, 0.3–0.5 mm wide, lanceolate or spatulate, membranous, semihyaline, ciliolate at apex. Staminate flowers subtended by bracteoles; pedicel 0.5–1 mm long, glabrous; stamens 4, inflexed. Pistillate flowers subtended by bracteoles, short pedicellate; sepals 3, minute; staminodes 3; stigma penicillate, ca. 0.25 mm long; ovary glabrous, straight, ovoid. Achenes ovoid, 8-ribbed, ca. 0.7 mm long, 0.3 mm wide.

Specimens examined: **TAIWAN**: Chiayi Co.: Kuanyin Water Fall, 22 Oct 1992, *H. F. Yen 6814* (HAST). Hsinchu Co.: Mt. Meiniaotsui, 25 Aug 2009, *Y. H. Tseng 1139* (TAI); Neiwan, 17 Oct 2009, *Y. H. Tseng 1144, 1145, 1146, 1147, 1148, 1149* (TAI); Youshueikeng, 30 Oct 2009, *Y. H. Tseng 1151, 1152* (TAI); Yanglao, 10 Oct 2010, *P. F. Lu 20955* (TAIF); Mt. Peitelaman, 13 Sep 2013, *C. F. Chen 4744* (TAIF); Mentoyu, 16 Aug 1925, *Simada 2400* (HAST); Yufeng Village, 14 Jan 2007, *P. F. Lu 13034* (HAST); Talu Forest Road, 11 Nov 2000, *C. I. Peng 18172* (HAST). Ilan Co.: Chialohu trail, 3 Jan 2010, *Y. H. Tseng 1154, 1155* (TAI); Nanshan, 3 Nov 2012, *Y. H. Tseng 1274* (TAI). Kaohsiung Co.: Maolin, 23 Oct 1991, *C. I. Ping et al. 14729* (TAIF); Meishankou, 6 Oct 2000, *C. I. Peng 18102* (HAST); Shanping Forest Recreation Area, 2 Dec 1996, *Y. H. Lai 68* (HAST). Miaoli Co.: Taian hotspring, 16 Nov 2002, *C. H. Yu 412* (HAST). Nantou Co.: Shenmu Village, 4 Feb 2010, *Y. H. Tseng 1161, 1162* (TAI). Tainan Co.: Mt. Kantou, *Y. H. Tseng 1277* (TAI); Nanshan, 2 Oct 1997, *S. C. Wu et al. 1473* (TAIF). Taichung Co.: Kukuan, 5 Oct 1981, *F. H. Fan s.n.* (TAIF). Taipei Co.: Bafu trail, 30 May 2009, *Y. H. Tseng 1114* (TAI); Mt. Wuliaochien, 2 Sep 2012, *P. F. Lu 24360* (TAIF). Taitung Co.: Chihpen logging trail, 9 Feb 2011, *Y. H. Tseng 1200* (TAI); Hsinwu, 10 Feb 2011, *Y. H. Tseng 1210* (TAI). Taoyuan Co.: Dongman trail, 28 Aug 2010, *Y. H. Tseng 1179* (TAI); Daman-bridge to Ssuling, 27 Oct 1997, *J. C. Wang et al. 10608* (TAIF); Mt. Hsinhsichou, 10 Sep 2011, *P. F. Lu 22858* (TAIF); Kapu, 9 Sep 2002, *S. C. Liu 777* (HAST); Niaojhueijian, 15 Sep 2001, *C. H. Chen 4059* (HAST); Hsiaowulai to Howei Ancient Tree, 9 Sep 2006, *P. F. Lu 12473* (HAST). Taitung Co.: Chilung Stream, 4 Nov 2002, *S. C. Liu & H. M. Chang 899* (TAIF); Shangwu, 17 Nov 1997, *S. Y. Lu 25322* (TAIF). **CHINA**: Fujian Prov.: Dapu, 13 Jul 1979, *M. S. Li 1040* (PE); Tianpingbanshan, 20 Jun 1986, *M. S. Li & Z. Y. Li 4455* (PE). Gansu Prov.: Fanba, 10 Sep 1964, *X. Q. Li & X. C. Zhao 2184* (PE); Bikougongshe, 9 Sep 1959, *Z. Y. Zhang 14758* (PE). Guangxi Prov.: Guangxi Botanical Garden, 18 Apr 2010, *Y. H. Tseng 1163, 1164, 1165, 1166* (TAI); Hezhou, 18 Apr 2010, *Y. H. Tseng 1169* (TAI); Mt. Damiao, 29 Aug 1958, *S. Q. Chen 15381* (IBK); Jiuwanshan, 22 Aug 1958, *S. Q. Chen 15265* (PE). Guizhou Prov.: Zijiangdifeng, 16 May 2012, *Y. H. Tseng 1261* (TAI, IBK); Daozhen, 12 Oct 1995, *Z. Y. Liu 15623* (PE). Hubei Prov.: Siqu, 27 Sep 1958, *H. J. Li 9271* (PE); Wudangshan, 7 Sep 1958, *K. R. Liu 155* (PE). Hunan Prov.: Langshan, 21 Aug 1994, *L. P. Luo 215* (PE); Shimen, 4 Jul 1987, *Hupingshan collection team 878* (PE); Nanmiao, 18 Aug 1985, *Y. P. Luo 3182* (PE). Sichuan Prov.: Mt. Qingcheng, 16 Aug 1975, *Z. Y. Wu 75-1224* (KUN); Nanchuan, 25 Nov 1996, *Z. Y. Liu 17939* (PE); Pingnanba, 8 Nov 1958, *Y. Q. He 1888* (PE); Dechang, 9 Sep 1959, *S. F. Zhu 20270* (PE); Fengjie, 3 Oct 1964, *H. F. Zhou & H. Y. Su 110703* (PE). Yunnan Prov.: Shilin, 7 Sep 1977, *Q. B. Yun 771050* (CDBI); Dajing, 23 Sep 1940, *Q. R. Chang 24865* (KUN); Yiliang, 7 Sep 1977, *Q. B. Yun 771208* (KUN); Panlong, 24 Oct 1939, *Q. W. Wang 84630* (KUN). **INDONESIA**: West Java Prov.: Mt. Gede-Pangrango, 29 Jul 2013, *Y. H. Tseng 1280, 1286* (TAI).

Elatostema microcephalanthum Hayata, Icon Pl. Formosan. 5: 59. 1916. "microcephalatha"; Wang, Bull. Bot. Lab. N. E. Forest. Inst., Harbin 4(7): 43. 1980. Yang *et al.*, Bot. Bull. Acad. Sin. 36: 266–268. 1995. Chen *et al.*, Fl. China 5: 141. 2003. Type: —TAIWAN. Chiayi Co.: Alishan, 1912, *Hayata s.n.* (syntype: TI photo!).

微頭花樓梯草 (cf. Yang *et al.*, 1995)

Elatostema yonakuniense Hatus., J. Geobot. 12: 34. 1963. Type: —JAPAN. Ryukyu Prov.: Yonakuni, 26–30 Oct 1959, *Hatusima 24298* (isotype: US photo!).

Perennial monoecious herbs. Stems ascending, branched, 10–20 cm tall, 0.5–3 mm across, brownish-red or brownish-green to green, glabrous. Leaves alternate, sessile to subsessile; lamina 0.8–6 cm long, 0.5–2 cm wide, asymmetrically narrowly obovate, ovate to obovate-lanceolate to elliptic, membranous, lateral veins 2–4 pairs; the upper surface green, sparely strigose or slightly dense hirsute, cystoliths 0.2–0.25 mm long, linear; the lower surface pale-green, sparely hirsute along veins; apex acute to acuminate, entire; base asymmetric, acroscopic half cuneate, basiscopic half rounded semi-cordate; margin coarsely serrate, teeth 1–3 on acroscopic margin, 3–5 on basiscopic margin; petioles 1–3 mm long; stipules 2, opposite, 1–3 mm long, 1.5–2 mm wide, narrowly lanceolate. Inflorescences unisexual, axillary. Staminate inflorescences long-pedunculate, 5–8 mm in diameter; peduncle up to 3 cm long, glabrous; receptacle narrowly oblong to lanceolate; bracteoles numerous, 1.5–2 mm long, ca. 0.5 mm wide, narrowly lanceolate, membranous, semihyaline. Pistillate inflorescences sessile to subsessile when blooming, pedunculate when fruiting, 3–6 mm in diameter, ellipsoidal; receptacle 1–6 mm long, 0.4–1 mm wide, lanceolate to oblong, slightly puberulent; bracteoles numerous, 0.5–1 mm long, 0.2–0.5 mm wide, lanceolate, membranous, semihyaline. Staminate flowers subtended by bracteoles; pedicel 1–1.5 mm long, glabrous; sepals 5, linear, narrowly triangular, apex obtuse to rounded; stamens 4, inflexed. Pistillate flowers subtended by bracteoles, short pedicellate; sepals 3 or 4, minute; staminodes 3 or 4; stigma penicillate; ovary glabrous, straight, ovoid. Achenes ovoid, 5- or 6-ribbed, ca. 0.7 mm long, 0.3 mm wide.

Specimens examined: **TAIWAN**: Hsinchu Co.: Mt. Wainiaotsui, 15 Dec 2002, *S. C. Wu 2646* (HAST). Hualien Co.: Chilaipa to Mt. Wuchiapeng, 20 Oct 2011, *T. C. Hsu 4890* (TAIF); Yuli, 28 Jun 2001, *T. T. Chen 11360* (TAIF). Ilan Co.: Fushan, 1 Oct 1999, *Y. P. Cheng 2757* (TAIF); Mt. Chingshui, 23 Aug 1988, *S. Y. Lu 23720* (TAIF); Provincial Rd. 9A at 1.2 km, 1 Oct 1999, *Y. C. Kao 852* (HAST); Shenmihu, 15 Aug 2003, *M. W. Jien 153* (HAST). Nantou Co.: Sun-link-see forest recreation area, 1 Oct 2006, *C. H.*

Chen 7907 (TNM). New Taipei City: Kankou, 22 Aug 1996, *Sasaki s.n.* (TAI); Wulai, 20 Sep 2008, *Y. H. Tseng 1100* (TAI); Manyueyuan forest recreation area, 14 Nov 1999, *C. C. Chen 7340* (TAIF); Shihpafen, 19 Sep 2009, *P. F. Lu 18921* (TAIF); Manyuehyuan forest recreation area to Mt. Peichatien, 5 Nov 2002, *C. I. Haung 1339* (HAST); Mt. Kuai to Fushan village, 22 Dec 1992, *C. C. Liao 1071* (HAST); Pinhsi, 8 Oct 1998, *C. C. Wang 54* (TNM). Pingtung Co.: the trail to Mt. Chihpenchu, 15 Oct 1993, *Y. R. Lin 231* (HAST). Taitung Co.: Mt. Wutou, 31 Aug 1932, *Suzuki 11098* (TAI); Chengkung, 28 Aug 2007, *T. C. Hsu 942* (TAIF); Mt. Tulan, 20 Nov 2005, *J. S. Wu 2340* (TNM). Taoyuan Co.: Dongman trail, 28 Aug 2010, *Y. H. Tseng 1183* (TAI); Mt. Lala, 30 Oct 2009, *Y. H. Tseng 1142, 1192* (TAI), 24 Jun 1987, *S. Y. Lu 22169* (TAIF); Mt. Nachieh, 28 Aug 2010, *T. C. Hsu 3127* (TAIF). **JAPAN**: Okinawa Prov.: vicinity of airport at Is. Yonakuni, 2 Oct 1973, *Furuse 4205* (K).

Elatostema oblongifolium Fu, Bull. Bot. Lab. N. E. Forest. Inst. Harbin 4(7): 26. 1980; Chen *et al.*, Fl. China 5: 136. 2003. (Type unseen).

長圓樓梯草 (cf. Chen *et al.*, 2003)

Pellionia bodinieri H. Lév., Rep. Sp. Nov. 11: 551. 1913.
Elatostema multicanaliculatum B. L. Shih & Yuen P. Yang, Bot. Bull. Acad. Sin. 36: 268. 1995. Type: —TAIWAN. Taoyuan Co.: Mt. Lala, 23 Oct 1994, *B. L. Shih 3226* (isotype: HAST!, TAI!, TAIF!).

Perennial herbs. Stems erect or ascending, branched or simple, with 5 or more longitudinal canals, 20–80 cm high, 0.5–12 mm across, brownish-red at lower part, glabrous. Leaves alternate, sessile to subsessile; lamina 5–22 cm long, 2.5–7 cm wide, asymmetrically elliptic to oblong, membranous, pinnately nerved, lateral veins 5–7 pairs; the upper surface green, glabrous or sparely hirsute, with dense cystoliths, 0.2–0.25 mm long, fusiform; the lower surface pale-green, puberulent along veins, cystolith absent; petioles 1–5 mm long; apex acuminate, entire; base asymmetric, acroscopic half cuneate, basiscopic half acute, or rounded to cordate; margin serrulate to coarsely serrate; stipules 2, opposite, caducous, 3–7 mm long, 0.2–2 mm wide, narrowly lanceolate. Female inflorescences sessile or subsessile, 5–12 mm in diameter, ellipsoidal-discoid, white-green, slightly hirsute outside; receptacle up to 10 mm long, 3 mm wide, broadly ovate to ovate; bracts connate; bracteoles numerous, ca. 0.8 mm long, narrowly lanceolate, membranous, semihyaline, ciliolate at apex. Pistillate flowers subtended by bracteoles; sepals 3 or 4, minute; staminodes 3 or 4; stigma penicillate; ovary glabrous, straight, ovoid, ca. 0.4 mm long. Achenes ovoid, 8-ribbed, ca. 0.8 mm long, 0.3 mm wide.

Specimens examined: **TAIWAN**: Miaoli Co.: Mt. Malabang, 4 Sep 2010, *Y. H. Tseng 1184* (TAI), 26 Dec 2010, *P. F. Lu 21189* (TAIF), 5 June 2005, *P. F. Lu 9856* (TAIF); Ssumahsien logging trail, 26 Jan 2011, *S. W. Chung 10195* (TAIF); Mt. Take, 3 Nov 2000, *C. N. Wang 04556* (TNM). Chiayi Co.: Jeitai old trail, 5 Nov 2006, *T. C. Hsu 640* (TAIF). Nantou Co.: Youshueikeng, 30 Oct 2009, *Y. H. Tseng 1150* (TAI), 25 Sep 2006, *T. C. Hsu 614* (TAIF); Shanlinehsi, 13 Oct 2010, *Y. H. Tseng 1195, 1196* (TAI); Yushanlun logging trail, 4 Sep 2011, *P. F. Lu 22815* (TAIF); Chunta logging trail 4–6 K, 25 Feb 2013, *P. F. Lu 25306* (TAIF); Chunta logging trail 9–11 K, 26 Nov 2012, *T. C. Hsu 6116* (TAIF). **CHINA**: Fujian Prov.: Nanping City, 14 Dec 1979, *G. S. He 288* (PE). Guizhou Prov.: Zijiangdifeng, 16 May 2012, *Y. H. Tseng 1263, 1268* (TAI, IBK); Zhengan Co., 20 Jun 1996, *Z. Y. Liu 12563* (PE); Duorao Twp., 11 Apr 2003, *L. D. Duan & Q. Lin 2002093* (PE). Hunan Prov.: Zixiadong, 15 Jan 2002, *L. D. Duan 2002052* (PE). Sichuan Prov.: Xinhe, 28 Apr 1964, *H. F. Zhou 107866* (IBSC); Ermei, 25 Nov 1940, *W. P. Fang 905579* (KUN); Mt. Ermei, 2 Nov 1964, *Sichuan collection team 2484* (PE); Doujiangyan City, 10 Sep 1986, *W. S. Wang s.n.* (PE); Sanjiatu, 13 Jan 1984, *Z. Y. Liu 4821* (PE); Huilong temple, 5 Oct 1995, *Z. Y. Liu 13955* (PE); Honghegou, 8 Oct 1996, *Z. Y. Liu 13362* (PE). Yunnan Prov.: Guangnan Co., 1 Feb 1993, *Y. M. Shui 1441* (PE).

Elatostema platyphyllum Wedd., Arch. Mus. Hist. Nat. 9(1): 301. 1856; C. B. Robison, Philipp. J. Sci. 3: 404. 1908; Tang and Huang, Fl. Taiwan 1st 2: 183. 1976; Chen *et al.*, Fl. China 5: 154. 2003. Type: —INDIA. Khasia, 10 Aug 1850, *Hooker & Thomson s.n.* (Lectotype: K!)

巒大冷清草 (cf. Liu and Huang, 1976)

Elatostema platyphylloides B. L. Shih & Yuen P. Yang, Bot. Bull. Acad. Sin. 36: 158. 1995. Type: —TAIWAN. Taitung Co.: Chihpen Logging Trail, 12 Mar 1994, *B. L. Shih 2598* (isotype: HAST!, TAI!, TAIF!).

Perennial monoecious or dioecious herbs. Stems woody at base, ascending, branched, 50–150 cm tall, 0.5–1 cm across, green, glabrous to slightly hirsute. Leaves alternate, sessile to subsessile; lamina 10–25 cm long, 4–7.5 cm wide, asymmetrically elliptic to oblong, chartaceous, lateral veins 4–6 pairs; the upper surface dark green to green, sparely strigose, cystoliths numerous, 0.3–0.4 mm long, linear; the lower surface pale-green to light green, hirsute along veins; apex caudate, densely serrulate; base asymmetric, acroscopic half cuneate, basiscopic half semi-sagittate with auriculate limb; margin serrulate, teeth 22–45 on acroscopic margin, 33–56 on basiscopic margin; petioles 0–5 mm long; stipules 2, opposite, caducous, 15–25 mm long, 3–5.5 mm wide, narrowly lanceolate, glabrous to hirsute. Inflorescences unisexual, axillary, slightly minutely puberulent outside. Staminate inflorescences solitary or in pairs, 15–30 mm in long, 10–25 mm in wide; peduncle 3–18 mm long, glabrous; receptacle up to 3 cm long, 1 cm wide, narrowly oblong to oblong; bract apex subulate, with horn-like projection; bracteoles 1–5 mm long, 1–3 mm wide, numerous, narrowly lanceolate, apex truncate or mucronate, membranous, semihyaline, with minuate cystoliths. Pistillate inflorescences sessile to subsessile, up to 7 × 6 mm in diameter, ellipsoidal, green; receptacle 6–7 mm long, 2–5 mm wide, discoid; bracteoles numerous, 0.5–0.9 mm long, 0.15–0.3 mm wide, cymbiform, membranous, semihyaline, ciliate at apex, minutely hirsute at margin. Staminate flowers subtended by bracteoles, pedicellate; sepals 4, 1.5–2.4 mm long, cymbiform, apex acute; stamens 4, inflexed.

Pistillate flowers subtended by bracteoles, short pedicellate; sepals 4, free, narrowly triangular, 0.1–0.3 mm long; staminodes 4; stigma penicillate; ovary glabrous, straight, ellipsoidal. Achenes ellipsoidal, 0.5–0.7 mm long, 0.3–0.4 mm wide, obscurely striate.

Specimens examined: **TAIWAN**: Chiayi Co.: Juili, 26 Feb 1997, *T. Y. A. Yang et al. 7840* (TAIF). Hualien Co.: Hopingnanshi, 1 Jan 1999, *T. T. Chen 9420* (TAIF); Lungyun Leisure Farm, 13 Feb 1995, *K. Y. Wang et al. 752* (TAIF); Mataian, 30 Jan 1999, *K. C. Yang & J. K. Lin 5360* (TAIF); Huiyuan, 20 May 2010, *W. Y. Fang 158* (TAIF). Ilan Co.: Fushan, 3 Mar 2004, *S. H. Su et al. 1372* (TAIF). Nantou Co.: Shenmu village, 4 Feb 2010, *Y. H. Tseng 1160* (TAI); Shanfeng, 20 Feb 1994, *Y. C. Lu & H. T. Hung 1334* (TAIF). New Taipei City: Sandiaoling, 9 May 2009, *Y. H. Tseng 1107* (TAI); Bafu trail, 22 Aug 2009, *Y. H. Tseng 1133* (TAI); Honghe valley, 13 Dec 2009, *Y. H. Tseng 1158* (TAI); Tatsukeng, 9 May 2000, *C. H. Chen 3223* (TAIF); Hsiaoyi, 31 Mar 2000, *S. C. Liu & C. H. Chen 254* (TAIF); Wantan, 16 Dec 2000, *C. T. Lu 469* (TAIF); Wulai, 1 Jul 1976, *K. J. Tang 1592* (TAIF). Miaoli Co.: Mt. Malabang, 4 Sep 2010, *Y. H. Tseng 1187* (TAI); Hapen Ancient Trail, 3 Mar 2011, *T. C. Hsu 3699* (TAIF). Pingtung Co.: Mt. Tahan, 21 May 1994, *T. T. Chen et al. 4364* (TAIF); Taimali, 21 Feb 2001, *Y. M. Huang 220* (TAIF). Taipei Co.: Tasikungkengshan, 15 Mar 1997, *H. L. Chiang 383* (TAIF). Taitung Co.: Provincial Hwy 23, 20K, 10 Feb 2011, *Y. H. Tseng 1204* (TAI); Taimali, 12 Jan 1995, *S. Y. Lu 24486* (TAIF). Taoyuan Co.: North Cross Highway, 4 Mar 1987, *S. Y. Lu 21144* (TAIF); Fuhsing, 16 Mar 2001, *S. M. Luo 198* (TAIF). **CHINA**: Hainan Prov.: Wuzhishan, 6 Nov 1954, *Hainan Eastern Team 563* (PE); 16 Sep 1932, *N. Q. Chen 43852* (PE). Yunnan Prov.: Chen-Kang Hsien, Mar 1936, *Q. W. Wang 72230* (IBSC); Shangpa, 13 Oct 1933, *X. T. Cai 54884* (KUN); Datoupo, 24 Apr 1985, *Xiangliao collection team 340* (KUN); Daqingshan, 10 Apr 2000, *S. G. Wu et al. 61* (KUN); Longling, 10 Jan 1934, *H. T. Tsai 55044* (PE). Xizang Prov.: Xirang, 27 Nov 1992, *H. Sun et al. 1687* (KUN); Madi, *H. Sun et al. 3207* (KUN); Longgang, 6 May 1983, *B. S. Li & S. Z. Chen 4523* (PE); Xiachayu, 31 Aug 1983, *B. S. Li et al. 7193* (PE).

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Appendix 1. Plant materials examined in this study.

Taxon	Voucher	Locality	Herbarium	Name after revised	GenBank accession no.
Elatostema acuteserratum	*Y. H. Tseng 1121*	Lanyu, Taitung, Taiwan	TAI		KM649977
	Pi-Fong Lu 23736	Pingtung, Taiwan	TAIF		KM649996
	Tian-Chuan Hsu 5693	Pingtung, Taiwan	TAIF		KM649995
Elatostema cyrtandrifolium	*Y. H. Tseng 1164*	Guangxi, China	TAI		KM650000
	Y. H. Tseng 1169	Guangxi, China	TAI		KM650001
	Y. H. Tseng 1286	Java, Indonesia	TAI		KM649997
Elatostema edule	*Y. H. Tseng 1119*	Lanyu, Taitung, Taiwan	TAI		KM649998
	Y. H. Tseng 1131	Lanyu, Taitung, Taiwan	TAI		KM649976
Elatostema garrettii	*P. Suvarnakoses 38824*	Thailand	K		KM649994
Elatostema grande	*I. R. Telfor 10363*	Australia	K		KM649991
Elatostema herbaceifolium	*Y. H. Tseng 1139*	Hsinchu, Taiwan	TAI	*Elatostema cyrtandrifolium*	KM649969
	Y. H. Tseng 1152	Nantou, Taiwan	TAI		KM649999
Elatostema hirtellipedunculatum	*Y. H. Tseng 1123*	Lanyu, Taitung, Taiwan	TAI		KM649971
Elatostema hypoglaucum	*Y. H. Tseng 1190*	Taoyaun, Taiwan	TAI		KM649993
Elatostema insulare	*A. C. Smith 8145*	Fiji	K		KM649990
Elatostema lineolatum var. *majus*	*Y. H. Tseng 1108*	New Taipei City, Taiwan	TAI		KM649970
Elatostema microcephalanthum	*Y. H. Tseng 1100*	New Taipei City, Taiwan	TAI		KM649979
	Y. H. Tseng 1192	Taoyaun, Taiwan	TAI		KM650004
Elatostema multicanaliculatum	*Y. H. Tseng 1150*	Nantou, Taiwan	TAI	*Elatostema oblongifolium*	KM649981
Elatostema oblongifolium	*Y. G. Wei & A. K. Monro 6622*	Guangxi, China	IBK		KM650005
	Y. G. Wei & A. K. Monro 6713	Guizhou, China	IBK		KM650003
Elatostema obtusum	*Boufford et al. 27415*	Sichuan, China	A		KM649983
Elatostema parvum	*Y. H. Tseng 1182*	Taoyaun, Taiwan	TAI		KM649984
Elatostema platyphylloides	*Y. H. Tseng 1107*	New Taipei City, Taiwan	TAI		KM649973
	Y. H. Tseng 1158	New Taipei City, Taiwan	TAI		KM650002
Elatostema rivulare	*Y. H. Tseng 1207*	Taitung, Taiwan	TAI		KM649972
Elatostema sp.	*Y. H. Tseng 1285*	Java, Indonesia	TAI		KM649992
Elatostema strigillosum	*Y. H. Tseng 1209*	Taitung, Taiwan	TAI		KM649975
Elatostema subcoriaceum	*Y. H. Tseng 1127*	Lanyu, Taitung, Taiwan	TAI		KM649988
Elatostema trilobulatum	*Y. H. Tseng 1191*	Taoyaun, Taiwan	TAI		KM649982
Elatostema japonicum	*Tsugaru 30727*	Kyoto, Japan	A		KM649978
Elatostema villosum	*Y. H. Tseng 1275*	Tainan, Taiwan	TAI		KM649974
Elatostema yakushimense	*Murata et al. 15490*	Yakushima Island, Japan	A		KM649980
Elatostema yonakuniense	*Miyoshi Furuse 4561*	Japan	K	*Elatostema microcephalanthum*	KM649989
Pellionia minima	*J. M. Hu s.n.*	Japan			KM649985
Pellionia radicans	*Y. H. Tseng 1168*	Guangxi, China	TAI		KM649986
Pellionia scabra	*Y. H. Tseng 1219*	New Taipei City, Taiwan	TAI		KM649987
Pilea japonica	*Y. H. Tseng 1214*	Taitung, Taiwan	TAI		KM649968