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Two new species of *Sedum* (Crassulaceae) from Taiwan

Chang-Tse LU[1,2], Hung-Wen LIN[1], Jenn-Che WANG[1,*]

1. Department of Life Science, National Taiwan Normal University, No. 88, Ting-Chow Rd., Sec 4, Taipei 11677, Taipei City, Taiwan.
2 Department of Biological Resources, National Chiayi University, No. 300, Syuefu Rd., Chiayi City 60004, Taiwan.
[*]Corresponding author's email: biofv017@ntnu.edu.tw

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ABSTRACT: Based on our morphological observation, we proposed two new *Sedum* species in Taiwan. *Sedum kwanwuense* sp. nov. resembles *S. morrisonense.* However, it differs from the latter in having flatter and longer leaves, and occurring in different habitat, the former growing on humid, rocky slopes under the forest and the latter living on dry rocky slopes beyond the forest. *Sedum taiwanalpinum* sp. nov. is similar to *S. brachyrinchum,* but it can be distinguished from the latter by sepal and leaf morphologies (leaf linear-oblong to linear vs. spathulate to linear-oblong, and sepal unequal to subequal, spreading when blossom vs. unequal in length, erect to oblique when blossom). Our observations were supported by a former phylogenetic study. In this paper, besides providing taxonomic descriptions and line drawings of the two new taxa, we also organize an update key to native and naturalized species in *Sedum* in Taiwan for aiding the identification.

KEY WORDS: Crassulaceae, phylogeny, *Sedum kwanwuense*, *Sedum taiwanalpinum*, Taiwan.

INTRODUCTION

Sedum L. is the most species-rich genus of the family Crassulaceae. The genus comprises ca. 420 species (Nikulin *et al.*, 2016) nearly cosmopolitan in distribution with the highest diversity in the Mediterranean Sea, Central America, Himalayas, and East Asia (Thiede and Eggli 2007).

In Taiwan, the species number of *Sedum* is so abundant (Ito *et al*., 2017). However, their succulent habit cause the difficulty in their classification when the plants become dry specimens. The taxonomic treatment of Taiwanese *Sedum* species is very inconsistent, after the pioneer's work (e.g. Brown, 1885; Hayata, 1908, 1912, 1913, 1916; Yamamoto, 1926; Yamamoto and Bartlett, 1932). Liu & Chung (1977) and Tang & Huang (1989, 1993) revised this genus of Taiwan successively. Both of them recognized 14 species in Taiwan, but only eight species are concordant in their taxonomic treatments. The great discrepancy between the previously taxonomic studies indicate that the taxonomic study of *Sedum* in Taiwan is still insufficient. Lin (1999) revised the Taiwanese *Sedum* again based on the gross morphology of plants, including the micro-morphology of pollen and seeds, and geographical distribution and ecological data. He confirmed some species that misapply or ignore in previous studies, such as *S. actinocarpum*, *S. arisanense* and *S. erythrospermum*, by leaf and sepal morphology, and habit. In addition, he also evaluated and proposed some new taxa, i.e. *S. brachyrinchum* var. *taiwanaplinum*, *S. morrisonense* var. *kwanwuense*, and *S. tarokoense*, but these new taxa left unpublished. Based on his study, one new species, *S. tarokoense* Lin & Wang was described from the limestone area in Taiwan (Lu e*t al*., 2013). Additionally, one naturalized species, *S. sarmentosum* Bunge, was documented (Su *et al*., 2014).

Recently, Ito *et al*. (2017) published a phylogenetic analysis of Taiwanese *Sedum* in which the taxa using for study followed Lin's (1999) classification. Their results supported the taxonomic treatment of Lin (1999). However, two new taxa, i.e. *S. brachyrinchum* var. *taiwanaplinum* nom. nud., and *S. morrisonense* var. *kwanwuense* nom. nud., from Taiwan which were firstly proposed by Lin (1999) and were lately used in the analyses of Ito *et al.* (2017) were still unpublished formally. Therefore, based on morphological information and nrITS DNA and cpDNA phylogenetic analyses from Ito *et al.* (2017), we validly describe these two new taxa in this study.

TAXONOMIC TREATMENT

Sedum kwanwuense H.W. Lin, J.C. Wang & C.T. Lu, ***sp. nov.*** **Type: TAIWAN:** Shei-Pa National Park: Kwanwu, Dalu logging trail, *H. W. Lin 1398* (Holotype: TNU!) **觀霧佛甲草 Fig. 1G-L**

Perennial fleshy herbs. Stems glabrous, usually reddish, decumbent below, erect upward, rooting at nodes, base usually with young branches, 12–15 cm high. Leaves alternate, approximate, densely arranged, usually spreading, oblong-lanceolate to lanceolate, 10–15 mm long, 2–3 mm wide, apex obtuse to acuminate, base obtuse, spurred, margin entire. Inflorescence in dense cymes, terminal, usually trifid. Flowers sessile. Bract leaf-like, oblong-lanceolate, 8–10 mm long, ca. 2 mm wide, gradually reduced. Sepals 5, basally connate, campanulate, lobes equal, ca. 3 mm long, oblong-linear, apex obtuse, crassula, glabrous, persistent until the carpels mature. Petals 5, lanceolate, 6–7 mm long, ca. 2

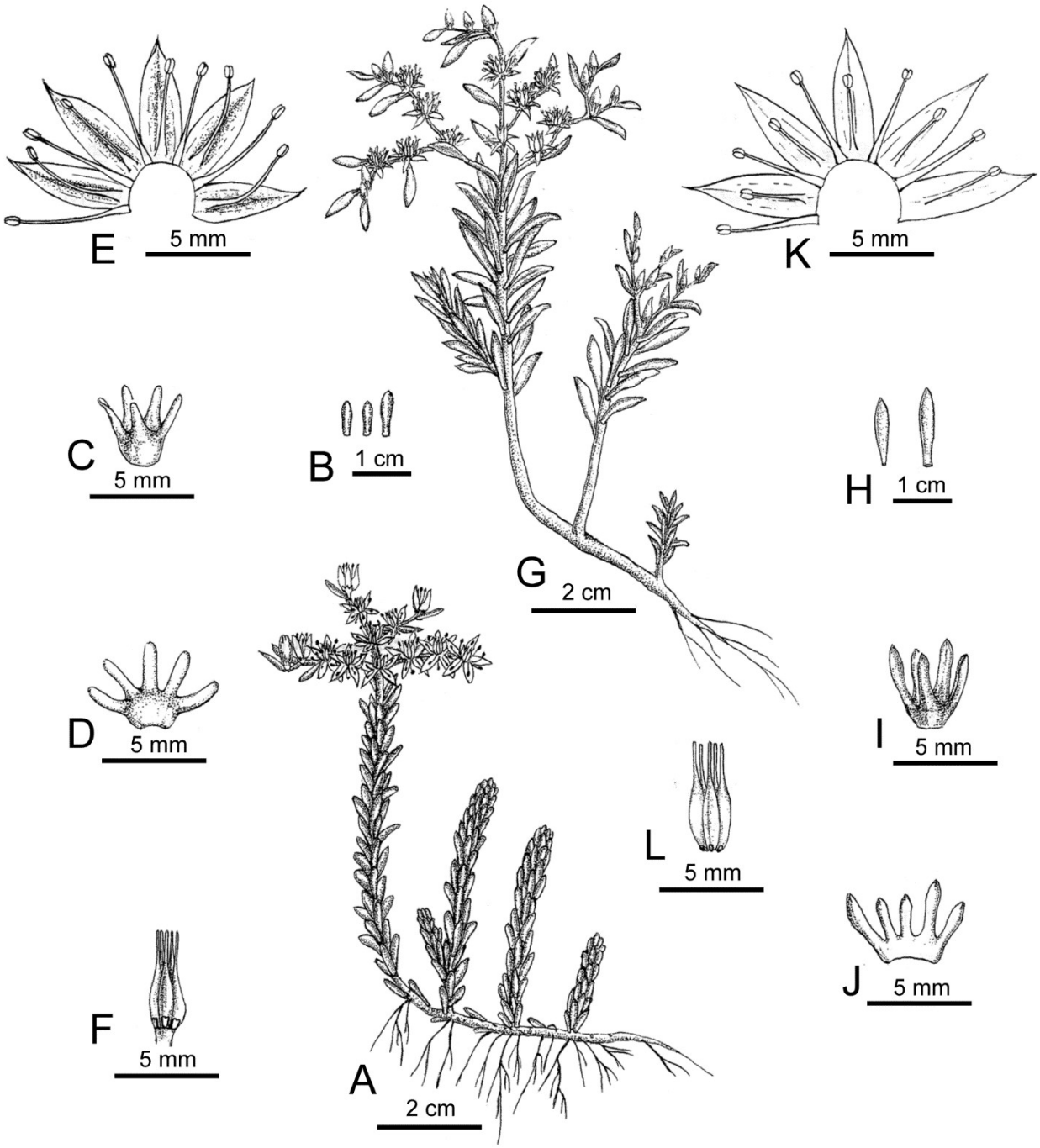

Fig. 1. Illustration of ***Sedum morrisonense*** Hayata (**A-F**) and ***S. kwanwuense*** H.W. Lin, J.C. Wang & C.T. Lu, sp. nov. (**G-L**). **A**, **G**. Habit. **B**, **H**. Leaves. **C**, **I**. Calyx. **D**, **J**. Calyx. **F**, **K**. Petals and stamens. **G**, **L**. Pistil.

Table 1. Comparison of diagnostics of ***Sedum morrisonense*** and ***S. kwanwuense***

characters	***S. morrisonense***	***S. kwanwuense***
Leaves	Terete; oblong-lanceolate to lanceolate; 6–8 mm × ca. 1.5 mm	Flat; oblong-lanceolate to lanceolate; 10–12(15) mm × 2–3 mm
Habitat	On high mountains at elevation above 2500 m; on dry rocky slope	Only find around Kwanwu, Hsichu. at altitude ca. 1800 m; on humid, rocky slope

mm wide, apex acuminate, base acute sometimes cuneate, yellow. Stamens 10, 2-whorled arranged. Anthers yellow, suborbicular to oblong. Filaments filiform, about 5 mm long. Glands 5, opposite to carpels, small. Carpels 5, free, connate in the base, oblong to oblong-lanceolate, about 5-6 mm long, glabrous, apex rostrate, styles about 1 mm long, Fruit follicles, oblong, ca. 5 mm. Seeds many in one follicle, 0.4–0.5 mm long, oblong, reddish brown when mature.

Distribution and habitat**:** Endemic to Taiwan. This new species is only known from Kwanwu, Hsinchu County and Ta-hsueh-shan logging trail, Taichung City,Taiwan (Fig. 3). It usually grows at rocky slope cracks under the forests.

Etymology: The epithet "kwanwuense" refers to the type locality of this new species.

IUCN Red List category**:** According to the specimens records, this species occurs in two areas (Kwanwu area, Hsinchu and Ta-hsueh-shan logging trail, Taichung). However, we only find it in the Kwanwu area now. We perform extent of occurrence (EOO) and area of occupancy (AOO) analysis using GeoCAT (Bachman *et al*., 2011; http://geocat.kew.org/) by imported specimen collection data. The result show that EOO is about 94 km^2 and AOO is about 16 km^2. According to the IUCN red list categories criteria (Editorial Committee of the Red List of Taiwan Plants, 2017), this species should be categorized as "Endangered" (EN B2ab(iv, v)).

Additional specimens examined: **TAIWAN.** Hsinchu County: Wufeng Hsiang: Lehshan, elev. ca. 1800 m, Jul. 24, 1987, *J. C. Wang & K. C. Yang s. n.* (TAI). Miaoli County: Taian Hsiang: Kwanwu, Da-lu logging trail, elev. ca. 2000 m, *J. C. Wang 8288* (TNU, HAST); same loc., *H. W. Lin 1398, 1443* (TNU); same loc., 28-35 K, elev. 2000–2300 m, *J. C. Wang 4849* (TAI); same loc., Jul. 24, 1987, *K. C. Yang & J. C. Wang s. n.* (TAI). Taichung City: Hoping District, Ta-hsueh-shan logging trail, elev. 2000–2300 m, *J. C. Wang 4977* (TAI).

Note: Lin (1999) treated *S. kwanwuense* as a variety of *S. morrisonense* (i.e. *S. morrisonense* var. *kwanwuense*, unpublished) because they are similar in flower morphology and seed micromorphology. However we found that they can be separated from each other by leaf size (10–12(15) × 2–3 mm vs. 6–8 × 1.5 mm) and leaf shape (spathulate vs. oblong-lanceolate), as well as the leaves of the former was flat and the leaves of the latter was terete (Table 1). Moreover, we did not find any morphological transition individuals between these two taxa. The phylogenetic analysis based on nrITS data as well as nrITS and cpDNA combined data (Ito *et al.,* 2017) showed that these two species located in the different monophyletic clades (see Ito *et al.,* 2017, Fig. 3 & Fig. 5). *Sedum morrisonense* var. *morrisonense*, *S. taiwanianum, S. truncatistigmum* and *S. hakonense* composed a high-support monophyletic clade [PP (Bayesian posterior probabilities) = 1.0, ML BS (Maximum likelihood analysis, Bootstrap value) = 99%], but *S. kwanwuense* together with the other Taiwan endemic species and *S. formosanum* constituted the other high-support monophyletic clade (PP = 1.0, ML BS = 95%) (see Ito. *et al.,* 2017, Fig. 3 & Fig. 5). The further ancestral distribution inferences with BBM analysis performed by Ito *et al.* (2017) showed that the ancestral distributions of each clade were respectively Japan (*S. morrisonense* var. *morrisonense* clade) and Eastern China (the other Taiwanese species clade). This result suggests that the origins of *S. kwanwuense* and *S. morrisonense* were different. According to the above morphological and phylogenetic results, we considered *S. kwanwuense* should be treated as a distinct species.

Sedum taiwanalpinum H.W. Lin, J.C. Wang & C.T. Lu, ***sp. nov.*** **Type: TAIWAN.** Taichung County, Shei-Pa National Park: Hsuehshantungfeng to 369 lodge, elev. ca. 3,100 m, *H. W. Lin et al. 1345* (Holotype:TNU!; Isotype: TAIF) **高山佛甲草 Fig. 2G-L**

Perennial fleshy herbs. Stems glabrous, decumbent below, erect upward, rooting at nodes, base usually with young branches, 10–12 cm high, sometimes up to 15–18 cm high. Leaves alternate, approximate, densely arranged, spreading, linear-oblong to linear, 10–12 mm long, ca. 3 mm wide, apex obtuse, base attenuate to truncate, spurred, margin entire. Inflorescence in dense cymes, terminal, usually two to three branched. Flowers sessile. Sepals 5, free, unequal to subequal, linear to oblanceolate-linear, the larger 5–6 mm long, ca. 1.2 mm wide, the smaller 3–4 mm long, 1 mm wide, apex round or obtuse, base attenuate to truncate, spreading when blossom, persistent until the carpels mature. Petals 5, lanceolate, 6–7 mm long, ca. 2 mm wide, apex acuminate, base sometimes cuneate, yellow. Stamens 10, 2-whorled arranged. Anthers yellow to orange-yellow, suborbicular to oblong. Filaments filiform, 5–6 mm long. Glands 5, opposite to carpels. Carpels 5, free, connate in the base, oblong to oblong-lanceolate, 5–6 mm long, glabrous, apex rostrate. Styles ca. 1 mm long, Fruit follicles, subcoriaceous. Seeds many in one follicle, small, 0.4–0.5 mm long, oblong, yellow to yellowish brown when mature.

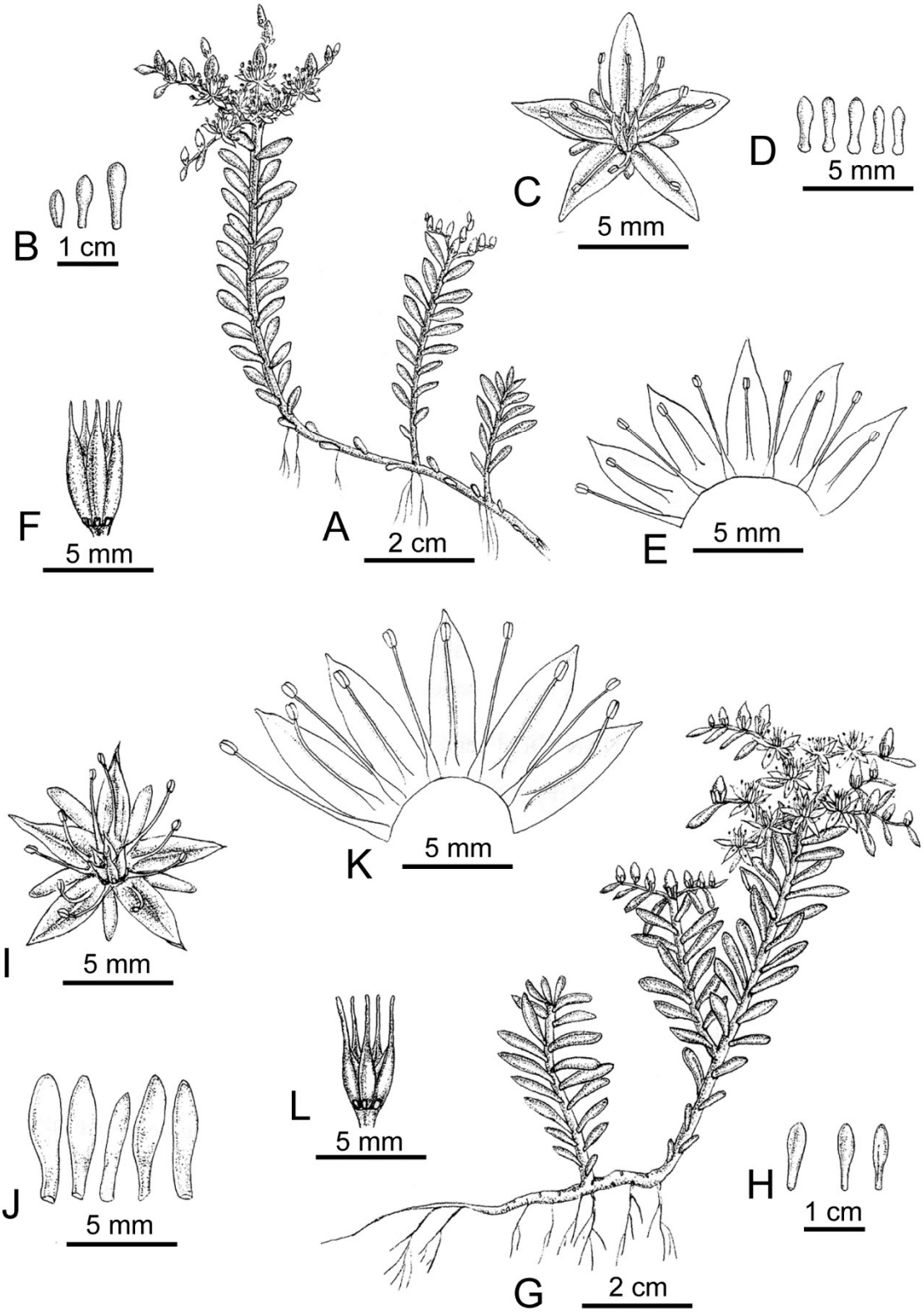

Fig. 2. Illustration of ***Sedum brachyrhinchum*** Yamamoto (**A-F**) and ***S. tawianalpinum*** H.W. Lin, J.C. Wang & C.T. Lu, sp. nov. (**G-L**). **A**, **G**. Habit. **B**, **H**. Leaves. **C**, **I**. Flower. **D**, **J**. Sepal. **E**, **K**. Petals and stamens. **F**, **L**. Pistil.

Table 1. Comparison of diagnostics of ***Sedum brachyrhinchum*** and ***S. taiwanalpinum***

characters	***S. brachyrhinchum***	***S. taiwanalpinum***
Leaves	Spathulate to linear-oblong, 6–8 mm long, ca. 3 mm wide	Linear-oblong to linear, 10–12 mm long, ca. 3 mm wide
Habitat	At elevation about 2000–3000 m; on rocky slope	Under forest at elevation about 3000–3500 m

Fig. 3. Distribution records of ***Sedum kwanwuense*** H.W. Lin, J.C. Wang & C.T. Lu, sp. nov. (triangle) and ***S. taiwanalpinum*** H.W. Lin, J.C. Wang & C.T. Lu, sp. nov. (circle) from Taiwan.

***Distribution and habitat*:** Endemic to Taiwan. It was usually found under the *Pinus* forest at the elevation of 3,000–3,200 m (Fig. 3).

Etymology: The epithet "taiwanalpinum" refers that this new species distributes on the high mountain area of Taiwan.

***IUCN Red List category*:** In present, this species occurs in Shei-Pa National Park and Taroko National Park. We consider that they are under no immediate threat of extinction. However, the species grows under the pine forest and will be affected by the decline of forests that caused by climate change in the future. Therefore, we consider it should be categorized as "NearThreatened", according to the IUCN red list categories criteria (Editorial Committee of the Red List of Taiwan Plants, 2017).

***Additional specimens examined*:** TAIWAN. Taichung City: Hoping Hsiang: Hsinta campus to Chihyushan to Taoshan, elev. 3000–3233 m, *J. C. Wang et al. 4050* (TAI); Wuling to Chika, sandy wet place, *T. C. Huang 7132* (TAI); Chikashanchuang to 369-shanchuang, shady grassland besides trail, elev. 2400–3100 m, *C. H. Chen 1342* (HAST); same loc., *C. C. Hsu 14638* (TAI); Hsuehshan, *C. M. Kuo 3953* (TAI); Mt. Tugitaka, *T. Hosokawa 2333* (TAI); Yunlengshanchuang to Shenmachienshan, under the *Pinus* forest, *H. W. Lin et al. 750* (TNU); en route from Yunleng Lodge to N-peak of Nanhutashan (a mountain), at rocky slope cracks, elev. ca. 3030 m, *C.-I Huang 2642* (HAST); Chiliting to Nanhushanchuang, in conifer forest, elev. 2780–3000 m, *C. C. Hsu 5921* (TAI); Nanhutashan, *Masamune et al. 2914* (TAI); same loc., *M. T. Kao 5258* (TAI). Nantou County: Jenai Hsiang: Hohuanshan, elev. ca. 3000 m, *S. S. Ying 4807, 4818* (TAI); same loc., on exposed slope, elev. 3050–3150 m, *C. H. Chen 1270* (HAST, TAIF); Tayuling to Hohuanshan, elev. 2565–3250 m, *C. C. Hsu 3819* (TAI); same loc., *C. S. Kuo 7052* (TAI). Hualien County: Hsulin Hsiang: en route from Heishuitang to Chengkung No. 2, 3 campsite, creeping on semi-shaded slope, elev. 2605–2775m, *H. Y. Shen 52* (HAST, TNU); Sungshuehlo to Chilaishanchuang, under the *Abies* forest, *H. W. Lin et al. 1393* (TNU); Kwarenko-tyo, Tyousenzan, Be Sipau no Sita, elev. ca. 2800 m, *Fukuyama & T. Suzuki ST 16242* (TAI); Tsu-wen, on rocks, *C. C. Chang 4394* (TAI).

Note: *Sedum taiwanalpinum* resembles *S. brachyrhinchum* but can be distinguished by sepal and leaf morphology (Lin, 1999). The morphological comparison showed that the leaves are linear-oblong to linear, 6–8 mm long in the former, but are spathulate to linear-oblong, 10–12 mm long in the latter (Table 2). Besides, the former has larger and spreading sepals while the latter has smaller and ascending ones. The phylogenetic analysis based on nrITS data (Ito *et al*., 2017) showed *S. brachyrinchum* together with *S. actinocarpum*, *S. triangulosepalum*, *S. tarokoense, S. nokoense, S. kwanwuense* and *S. taiwanalpinum* composed a medium-support monophyletic clade (PP = 0.75, ML BS = 68%). This clade supported that *S. taiwanalpinum* and *S. brachyrinchum* were separated into two different subclades. One subclade comprised *S. brachyrinchum, S. actinocarpum*, *S. triangulosepalum* and *S. tarokoense* (PP = 0.52, ML BS = 62%), while the other subclade consisted of *S. taiwanalpinum, S. nokoense* and *S. kwanwuense* (PP = 0.98, ML BS = 88%) (see Ito *et al.* 2017, Fig. 3). Besides *S. brachyrhinchum* was usually found on dry, rocky slope, but *S. taiwanalpinum* found in the *Pinus* forest.

Therefore, we concluded that *S. taiwanalpinum* should be considered as a distinct species

The key to native and naturalized species of genus *Sedum* L. in Taiwan is provided below for the aid of identification. Most of the scientific names used here is based on the taxonomic treatment of Lin (1999), Lu *et al.* (2013) and this study. *Sedum japonicum* subsp. *oryzifolium* var. *oryzifolium* is previously regarded as *S. uniflorum* Hook. & Arn. in Flora of Taiwan 2nd Edition (Tang & Huang, 1993) and *S. uniform* var. *oryziflorum* (Makino) H. Ohba in Lin (1999). According to the most recent research by Ohba (2003), he suggested using this scientific name and we follow his opinion.

Key to native and naturalized species of *Sedum* L. in Taiwan:

1a. Plant with glandular hairs; inflorescence paniculate; carpel not gibbous on ventral side ……..……... 2
1b. Plant glabrous; inflorescence cymose; carpel gibbous on ventral side .....…… 3
2a. Leaves 2-6 cm long, 1.5-2.5 cm wide; petals white ……..…….. ***S. drymarioides***
2b. Leaves 0.8-1.2 cm long, 0.5 cm wide; petals light yellow …… ***S. stellariifolium***
3a. Leaves 5 mm long or less ……. 4
3b. Leaves more than 5 mm long ……..... 5
4a. Leaves cylindric-oblong, thin; sepals linear, base not attenuate, erect at anthesis; petals spathulate …… ……. ***S. japonicum*** subsp. ***oryzifolium*** var. ***oryzifolium***
4b. Leaves spheroid, round to elliptic, thick; sepals linear-spathulate; petals lanceolate ……..…… ***S. tarokoense***
5a. Leaves spathulate or ovate-lanceolate; the largest sepal spathulate to oblong-spathulate ..……..…… 6
5b. Leaves oblong, oblanceolate or linear; sepals oblanceolate or linear ……..…… 14
6a. Plant creeping; leaves ovate-lanceolate, apex acute, three leaves whorled ……..……..…… ***S. sarmentosum***
6b. Plant erect or decumbent; leaves spathulate, apex obtuse, opposite or alternate ……..…… 7
7a. Plants decumbent below, ascending or erect upward …… 8
7b. Plant erect or sometimes with short decumbent stems ……..…. 10
8a. Plants without glandular dots on stem; stem usually greenish ……..…… ***S. sekiteiense***
8b. Plants with glandular dots on stem; stem usually reddish ……. 9
9a. Sepals free …… ***S. nokoense***
9b. Sepals connate at base …..…….…..... ***S. taiwanianum***
10a. Plant with bulbils on leaf axillary ……..… ***S. bulbiferum***
10b. Plant without bulbils ……..……..…… 11
11a. Plant with short decumbent stems, stem slender, internodes long, up to 4 cm ……..……..……. ***S. arisanense***
11b. Plant erect; stem strong; internodes short, less than 2 cm …..... 12
12a. Follicles erect when ripen; grow on seashore region … ***S. formosanum***
12b. Follicles wide-spreading when ripen; grow on mountainous region 13
13a. Leaves usually alternate; sepals larger, up to 5-6 mm long, ovate-spathulate, flat …….…..... ***S. actinocarpum***
13b. Leaves usually opposite; sepals smaller, 3-4 mm long, spathulate to oblanceolate to linear, thick ……..……. ***S. erythrospermum***
14a. Leaves verticillate, sometimes opposite ….…… ***S. mexicanum***
14b. Leaves alternate or densely arranged 15
15a. Leaves 1.5-2.5 cm long ……. 16
15b. Leaves 1 cm long or less ……..……..... 17
16a. Sepals 4-5 mm (the largest), free, linear …… ***S. microsepalum***
16b. Sepals 1-2 mm long, base connate, lobes triangular …….. ……..…… ***S. triangulosepalum***
17a. Sepals 1 mm or less, nearly wholly connate, broad-campanuate in shape …….…..... ***S. truncatistigma***
17b. Sepals more than 2 mm long, free or partly connate ……..…. 18
18a. Sepals connate at base ……..……..…… 19
18b. Sepals free ……..……..... 20
19a. Leaves 6-8 mm long ……..……. ***S. morrisonense***
19b. Leaves 10-12 mm long ……..……. ***S. kwanwuense***
20a. Sepals 2-3 mm long, ascending when blossom …… ……... ***S. brachyrhinchum***
20b. Sepals 4-5 mm long or more, spreading when blossom ……... ……... ***S. taiwanalpinum***

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