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Review

Taxonomy of *Epimedium* (Berberidaceae) with special reference to Chinese species

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ABSTRACT

Epimedii Herba is a commonly used traditional Chinese herbal medicine. Five *Epimedium* species are included in Chinese Pharmacopoeia and most species of *Epimedium* are used as *Epimedii Herba* in practical application. However, as the largest herbaceous genus of the Berberidaceae, *Epimedium* has many taxonomic controversies which hinder the effective use of *Epimedii Herba*. This paper reviewed the taxonomic research related to *Epimedium*, including taxonomic history, taxonomic values of morphological characters, species and distribution, infra-genera taxonomic system and the taxonomic research of Chinese *Epimedium*. For instance, we recognized *Epimedium wushanense* and clarified that the species, as described in *Flora Reipublicae Popularis Sinicae* and *Flora of China*, actually includes four *Epimedium* species similar in leaflet shape. In general, it was recognized here that *Epimedium* comprises 62 species, of which 52 species are distributed in China. For Chinese *Epimedium* species with the most taxonomic problems, the taxonomic research on the taxa was reviewed and the newest species key was proposed along with proposals for those taxonomic problems needing further resolution. This review is of great implication for the identification, exploration and utilization of *Epimedii Herba*.

Contents

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1. Introduction

Epimedium L. is the largest herbaceous genus of the Berberidaceae with its distribution centre and diversity centre in China. *Epimedium* plants have been used as Chinese herbal medicines for more than 2000 years. Five *Epimedium* species, *E. sagittatum* Maxim., *E. pubescens* Maxim., *E. brevicornu* Maxim., *E. koreanum* Nakai and *E. wushanense* T. S. Ying, are included in *Chinese Pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020). Guo et al. (2003) estimated that more than 20 *Epimedium* species might be used as *Epimedii Herba* in practical applications. At present, almost species of *Epimedium* with active ingredients (such as total flavonoids, epimedin A, epimedin B, epimedin C, and icariin) are used as *Epimedii Herba*. *Epimedii Herba* has been identified as having good curative effects for sexual dysfunction, osteoporosis, cardiovascular diseases, menstrual irregularity, asthma, chronic nephritis, cancer, decreased immunity and so on (Ma et al., 2011; Jiang, Song, & Jia, 2015; Indran et al., 2016; Tan et al., 2016; Xi et al., 2018). There are dozens of variants of medicines with *Epimedii Herba* as raw materials (Yu et al., 2018).

Although having great commercial prospects, *Epimedium* plants have abundant morphological variations and relatively more taxonomic controversies, which lead to the confusion in the use of *Epimedii Herba* and influence the research and development of the taxon. For instance, Guo et al. (2007) proposed that *E. wushanense* was a species with similar leaf shapes and various flower characters. Zhang et al. (2014) recognized *E. wushanense* and clarified that the species, described in *Flora Reipublicae Popularis Sinicae* (Ying, 2001) and *Flora of China* (Ying, Boufford, & Brach, 2011), includes four *Epimedium* species similar in leaflet shape. Xu et al. (2016) reported two new distribution localities of *E. epsteinii* Stearn. In contrast, we found that the species distributed at the two localities were *E. leptorrhizum* Stearn, which obviously differed from *E. epsteini* in terms of foliar and flower characters. In the present paper, we systematically reviewed the taxonomic studies of *Epimedium*. The history of taxonomic research and taxonomic values of morphological characters of *Epimedium* were analyzed and discussed. Phylogenetic research of *Epimedium* was sorted out and further research focus was proposed. As Chinese *Epimedium* had many taxonomic confusiones, the progress in taxonomy of Chinese *Epimedium* was reviewed and the newest species key was proposed along with proposals for those taxonomic problems needing further resolution. This review is meaningful for the taxonomic studies of *Epimedium* and the plant origin identification of *Epimedii Herba*, as well as for the exploration and utilization of the herbal medicines.

2. History of taxonomic research on *Epimedium* species

Linnaeus (1753) established *Epimedium* and named the first species of the genus, *E. alpinum* L., which is distributed in the Balkan peninsula and in the southern valleys of the Alps. Morren and

Table 1
System of classification proposed by different researchers and number of *Epimedium* species in different years.

Morren and Decaisne (1834)	Fischer and Meyer (1846)	Baillon (1862)	Franchet (1886)	Komarov (1908)	Stearn (1938)	Stearn (2002)
Sect. *Microceras* (four species)	Sect. *Microceras* (three species)	Sect. *Microceras* (three species)	Subg. *Euepimedium* (10 species)	Subg. *Euepimedium* (16 species)	Sect. *Rhizophyllum* (two species)	Subg. *Rhizophyllum* (two species)
Sect. *Macroceras* (three species)	Sect. *Macroceras* (four species)	Sect. *Macroceras* (four species)	Sect. *Phyllocaulon* (eight species)	Sect. *Gymnocaulon* (three species)	Sect. *Phyllocaulon* (19 species)	Subg. *Epimedium* (52 species)
	Sect. *Rhizophyllum* (one species)	Sect. *Dimorphophyllum* (two species)	Sect. *Gymnocaulon* (two species)	Sect. *Phyllocaulon* (13 species)	Subsect. *Monophyllon* (four species)	Sect. *Diphyllon* (43 species)
		Sect. *Aceranthus* (one species)	Subg. *Vancouveria* (one species)	Ser. *Monophyllam* (three species)	Ser. *Microcerae* (two species)	Ser. *Campanularae* (four species)
				Ser. *Aceranthus* (one species)	Ser. *Macrocerae* (two species)	Ser. *Davidianae* (10 species)
				Ser. *Diphyllonm* (seven species)	Subsect. *Aceranthus* (three species)	Ser. *Dolichocerae* (16 species)
				Ser. *Polyphylla* (two species)	Subsect. *Diphyllon* (10 species)	Ser. *Brachycerae* (13 species)
				Subg. *Vancouveria* (three species)	Ser. *Dolichocerae* (six species)	Sect. *Macroceras* (six species)
					Ser. *Brachycerae* (four species)	Sect. *Polyphyllon* (one species)
					Subsect. *Polyphyllon* (two species)	Sect. *Epimedium* (two species)
					Ser. *Elongatae* (one species)	
					Ser. *Elatae* (one species)	
seven species	eight species	10 species	11 species	19 species	21 species	54 species

Decaisne (1834) published the first monograph of *Epimedium* in which the genus was recognized with seven species and in which the *Epimedium* species from Japan and western Asian were introduced for the first time (Table 1). In their monograph, *Epimedium* was divided into two sections: sect. *Macroceras* C. Morren & Decne. and sect. *Microeras* C. Morren & Decne. Sect. *Macroceras* included three Japanese species bearing large flowers and petals with long spurs, *E. macranthum* C. Morren & Decne, *E. violaceum* C. Morren & Decne and *E. musschianum* C. Morren & Decne. Sect. *Microeras* bore large flowers and short spurred petals, including *E. alpinum*, *E. pubigerum* C. Morren & Decne and *E. pinnatum* Fisch. from the European Mediterranean and *E. elatum* C. Morren & Decne from Kashmir. In this monograph, the two researchers published two new monotypic genera: *Aceranthus* C. Morren & Decne was for spurless Japanese species *A. diphyllum* Graham, while *Vancouveria* C. Morren & Decne was for *V. hexandra* C. Morren & Decne from western North America.

Fischer and Meyer (1846) published the second monograph of *Epimedium*. In their monograph, the two botanists recognized eight *Epimedium* species, accepted the system of Morren and Decaisne (1834) and treated *E. pinnatum* as a new section of *Epimedium*, sect. *Rhizophyllum* Fisch. & C. A. Mey., which differed from other sections of the genus by its inflorescence lacking leaflets (Table 1). In the third monograph of *Epimedium*, Baillon (1862) retained the three sections of the system of Fischer and Meyer (1846), but renamed sect. *Rhizophyllum* as sect. *Dimorphophyllum* Baillon and adjusted the genus *Aceranthus* as a new section of *Epimedium* (Table 1). Cosson (1862) published the other species of sect. *Rhizophyllum*, *E. perralderianu* Coss., from western North Africa. There had been ten species of *Epimedium* reported in 1862. Maximowicz (1877) described the first Chinese species of *Epimedium*. Since then, the rich diversity of Chinese *Epimedium* became gradually recognised.

Franchet (1886) published the fourth monograph of *Epimedium*, in which he adjusted *Vancouveria* as one subgenus of *Epimedium*, subg. *Vancouveria* Franch, treated previous *Epimedium* as other subgenera, subg. *Euepimedium* Franch. and recognised 11 *Epimedium* species, including one species of subg. *Vancouveria* and four species of subg. *Euepimedium* from China. Furthermore, subg. *Euepimedium* was divided into two sections, sect. *Phyllocaulon* Franch. and sect. *Gymnocaulon* Franch., and sect. *Gymnocaulon* was the same as sect. *Rhizophyllum* of the system of Fischer and Meyer (1846) and as sect. *Dimorphophyllum* of the system of Baillon (1862) (Table 1). Komarov (1908) recognised 19 *Epimedium* species and proposed the fifth taxonomic system of the genus. Komarov's (1908) system accepted Franchet's (1886) classification and further divided sect. *Phyllocaulon* into four series mainly based on the number of cauline leaves. Ser. *Monophyllam* Kom. was with one cauline leaf which included *E. alpinum* and *E. pubigerum* from the Mediterranean and *E. macranthum* from Japan. Ser. *Aceranthus* Kom. bore one cauline leaf with only two leaflets and was same as sect. *Aceranthus* of Baillon's (1862) system which had only one species, *E. diphyllum*. Ser. *Diphyllonm* Kom. was mainly with two opposite leaves and comprised of seven Chinese species, such as *E. pubescens*, *E. acuminatum* Franch. and *E. brevicornu*. Ser. *Polyphylla* Kom. was with several alternative leaves which included *E. elatum* from western Asian and *E. elongatum* Kom. from China. Furthermore, subg. *Vancouveria* had been increased to three species in the system (Table 1).

Stearn (1938) published an excellent monograph: *Epimedium* and *Vancouveria* (Berberidaceae). In the monograph, subg. *Vancouveria* was treated as an independent genus *Vancouveria*, which was consistent with the primary treatment when the first *Vancouveria* species was recorded (Morren & Decaisne, 1834). Furthermore, *Epimedium* was divided into two sections, sect. *Rhizophyllum* and sect. *Phyllocaulon*. The four series of sect. *Phyllocaulon* of Komarov's (1908) system were also adjusted into four sections, three of which were divided into two series based on geographical distribution. So far, 21 *Epimedum* species were recognised with 13 species distributed in China (Table 1). With his increased knowledge about *Epimedium*, especially for Chinese *Epimedium*, Stearn (2002) proposed the most recent classification system of *Epimedium*, which adjusted the two sections of Stearn's (1938) system into two subgenera, subg. *Rhizophyllum* (Fisch. & C. A. Mey.) Stearn and subg. *Epimedium*. According to its geographical distribution, subg. *Epimedium* was divided into four sections. Sect. *Diphyllum* (Kom.) Stearn comprised *Epimedium* species endemic to China and was divided into four series based on flower characters. In this monograph, 54 *Epimedium* species were recognised with 44 species distributed in China (Table 1).

Epimedii Herba was first recorded as an aphrodisiac in *Shennong's Herbal Classic* published in Chinese Eastern Han Dynasty or earlier (Sun, 2017). The other functions of *Epimedii Herba*, such as strengthening bones and muscles, treating rheumatism, relieving cough and asthma and so on, had gradually been recognized in Chinese ancient herbal medicine books (Jiao et al., 2017). The distribution regions of *Epimedii Herba*, Northern Xichuan (Shaanxi), Shangjun (Yuli and Yan'an of Shaanxi, Mashen banner of Inner Mongolia), were firstly described in *Collective Notes to Canon of Materia Medica* of Chinese Liang Dynasty (Shang & Shang, 1994). More distribution regions of *Epimedii Herba* were also recorded in *Illustrated Classics of Materia Medica* of Chinese Song Dynasty (Hu & Wang, 1988), such as Yongkangjun (Dujiangyan, Sichuan), Yizhou (Lanshan, Shandong), Jiangdong (Jiangsu, Zhejiang and Jiangxi), Shaanxi (Shaanxi, Ningxia, Henan and Gansu), Taishan (Tai'an, Shandong), Hanzhong (Hanzhong, Shaanxi) and Huxiang (Wuxing of Zhejiang and Hunan). Furthermore, although having no species concept, Chinese ancient herbalists noted the morphological diversity of *Epimedii Herba*. For instance, *Illustrated Classics of Materia Medica* (Shang & Shang, 1994) recorded that *Epimedii Herba* was with white or purple flowers and defoliate except those from Huxiang which were evergreen. *Compendium of Materia Medica* of Chinese Ming Dynasty (Wang, 1999) described that each stem of *Epimedii Herba* bore one branch with three leaves, while *Materia Medica Chongyuan* of Chinese Qing Dynasty (Zhang & Wu, 2011) recorded that each stem of the herb bore three branches with three leaves.

As the first Chinese botanist who systematically researched *Epimedium*, Ying (1975) reviewed Chinese *Epimedium*, recognising China as possessing 13 *Epimedium* species with two new species, and treating *E. membranceum* K. Mey. as a synonym of *E. davidii* Franch. and *E. fargesii* Franch. as an insufficiently known species. Subsequent taxonomic progress had led to the publication of more than 40 *Epimedium* species endemic to China. Flora and illustrated handbooks about Chinese *Epimedium* have been gradually published, including *Flora Reipublicae Popularis Sinicae* (Ying, 2001), *Flora of China* (Ying, Boufford, & Branch, 2011) and *the Genus Epimedium of China in Colour* (He, 2014). *Epimedium* has relatively abundant variations of inter- and infra- species and many new Chinese species have been published over the past 40 years, which has brought about new taxonomic questions on Chinese *Epimedium*. Researchers have carried out taxonomic revisions on Chinese taxa based on morphological and molecular phylogenetic data (Zhang et al., 2011, 2014a, 2014b, 2015a, 2015b; He 2014; Liu et al., 2017a; Liu et al., 2017b).

3. Taxonomic values of morphological characters of *Epimedium*

3.1. Rhizome

Epimedium is a genus of perennial woodland herbs. The morphological characters of rhizome, foliage, inflorescence and flowers are often used to discriminate different *Epimedium* species. The form of the rhizome, i.e. the degree of elongation and thickness,

is relatively stable for each *Epimedium* species. For example, *E. fangii* Stearn, *E. pauciflorum* K.C. Yen and *E. perralderianum* Coss. have long-creeping and thread-like rhizomes, 1–3 mm in diameter. In contrast, *E. diphyllum* has short-creeping rhizomes with a diameter of 3–5 mm. Furthermore, the rhizomes of *E. wushanense*, *E. sagittatum* and *E. borealiguizhouense* S. Z. He & Y. K. Yang are usually stouter and more compact and are sometimes more than 1 cm thick.

3.2. Stem

Although the stem of *Epimedium* is terete, wiry, and shows little variation, its indumentum is specific for some *Epimedium* species. For instance, the stem of *E. baojingense* Q. L. Chen & B. M. Yang has dark yellow pubescent hairs, while that of *E. glandulosopilosum* H. R. Liang has multi-cellular glandular hairs and golden-yellow villi.

3.3. Foliage

The foliage of *Epimedium* is so characteristic that the genus may be recognised by its foliage alone (Stearn, 2002). The number of leaflets, the number of leaves on the flowering stem and the morphology of leaflets are important taxonomic characters of *Epimedium*. For the number of leaflets, *E. elachyphyllum* Stearn and *E. muhuangense* S. Z. He & Y. Y. Wang are the only two species in *Epimedium* which have leaves consisting of a single leaflet. *E. perralderianum* and most species of sect. *Diphyllon* (Kom.) Stearn usually bear trifoliolate leaves. *E. diphyllon* has an unusual modification of the trifoliolate leaf, showing that the terminal leaflet is suppressed and its leaf consists of two lateral leaflets. *E. davidii* has 5- or 3-foliolate leaves while *E. ecalcaratum* G. Y. Zhong bears leaves with three, five, or seven leaflets. *E. brevicornu*, *E. xichangense* Y. J. Zhang, *E. koreanum*, *E. sempervirens* Nakai ex F. Maek., *E. alpinum*, *E. pubigerum* and *E. pinnatum* usually have biternate leaf with nine leaflets. *E. elatum* bears ternately compound leaves with the larger leaves having 50 or more leaflets. Stearn (2002) proposed that the leaves of *Epimedium* might have evolved from compound to simple, which is contrary to the hypothesis on the evolution direction of the leaflet number of *Epimedium* suggested by Ying (2002). The evolution direction of the number of leaflets needs further research and the future system of the genus may be revised to some extent based on the leaflet number.

The number of leaves on the flowering stem has been used in identifying the *Epimedium* species and infra-genera grouping of the genus (Fischer von & Meyer, 1846; Baillon, 1862; Franchet, 1886; Komarov, 1908; Stearn, 1938, 2002). In the updated system of *Epimedium* (Stearn, 2002), subg. *Rhizophyllum* has no leaves on the flowering stem, while subg. *Epimedium* has one, two, three or even up to eight stem leaves. For four sections of subg. *Epimedium*, sect. *Macroceras* and sect. *Epimedium* have one leaf borne on the flowering stem. Sect. *Diphyllon* often has two stem leaves or sometimes three leaves (*E. elongatum*) and sometimes one leaf (*E. leptorrhizum*). Sect. *Polyphyllum* (Kom.) Stearn comprises only *E. elatum*, with three to eight ternately compound stem leaves.

The morphology of leaflets, such as shape and indumentum, is usually used to classify *Epimedium* species. The leaflet shape of *Epimedium* ranges from nearly orbicular, broadly ovate, ovate, narrowly ovate, lanceolate, to narrowly lanceolate. The base of leaflets is usually cordate with rounded, acute or acuminate basal lobes, except that of *E. truncatum* H. R. Liang which has almost truncated basal lobes (Fig. 1A–F). Although some *Epimedium* species have variations in leaflet shape, the leaflet shape is relatively stable for every *Epimedium* species and can be used for classification of the genus. The adaxial surface of the leaflet of *Epimedium* is always glabrous except for *E. dolichostemon* Stearn, *E. diphyllon* and *E. pinnatum*. The abaxial surface has many kinds of indumentum or glabrous types. Similar to leaflet shape, the indumentum of the leaflet is characteristic for different *Epimedium* species and some species have several indumentum types (Zhang et al., 2011, 2015b; Xu et al., 2013; Liu et al., 2017b). For instance, the adaxial surface of leaflets of *E. dolichostemon* is glabrous or pubescent, the indumentum on the abaxial surface of the leaflets of *E. borealiguizhouense* varies from densely strigose to densely pubescent, to lanose and to glabrous (Zhang et al., 2015b).

3.4. Inflorescence

Epimedium has two kinds of inflorescence, raceme (Fig. 1G) and panicle (Fig. 1H–L). Some species, for example *E. pauciflorum*, *E. platypetalum* K. Mey., *E. franchetii* Stearn, have stable raceme. For the *Epimedium* species with panicle, the inflorescences of some species have one-flowered upper pedicels and several-flowered lower peduncles (e.g. *E. mikinorii* Stearn, *E. acuminatum*, *E. elachyphyllum*), which may be a simple raceme in younger plants or, in the worst case, for some of the species (e.g. *E. acuminatum*, *E. elachyphyllum*). Those of other species fully consist of several-flowered peduncles (e.g. *E. sagittatum*), whose flower number of peduncle and the width of inflorescence vary among different species and even among different populations of the same species. In fact, the inflorescence of *Epimedium* is an inexact indefinite inflorescence. Although the inflorescence blooms from bottom to top on the whole, the top flower of each peduncle of the inflorescence always blooms earlier than the preceding lower two flowers.

3.5. Flower

Flower characters of *Epimedium*, such as flower dimension, petal type, the form and relative size of the inner sepals and petals, are mostly stable and specific for every species, which have important taxonomic values for species identification (Fig. 2A–P). Researchers also used these flower characters for classifying infra-genera groups (Morren & Decaisne, 1834; Fischer von & Meyer, 1846; Stearn, 1938, 2002). In the updated system of *Epimedium* (Stearn, 2002), sect. *Diphyllon* was divided into four series based on flower characters, especially on petal characters. Series *Campanulatae* Stearn has small campanulate flowers whose petals are flat or with a slight nectarial swelling at the base (Fig. 2A–B). Series *Davidianae* Stearn has large flowers with the petal possessing an elongated curved spur and a basal lamina (Fig. 2C–F). Series *Dolichocerae* Stearn also has large flowers whose petal bears long spurs without basal lamina (Fig. 2G–I). Series *Brachycerae* Stearn has usually 1–4 mm long, short-spur or slipper-shaped petals, which are much shorter than the inner sepal (Fig. 2J–P). Stearn (2002) and Ying (2002) proposed two different petal evolution routes of *Epimedium*, both which considered that the *Epimedium* species with flat petals or with a slight nectarial swelling at the base were the most primitive taxa of the genus (Fig. 2A–B). However, Stearn (2002) considered that *Epimedium* species evolved from the most primitive petals to long-spur petals with basal lamina (Fig. 2C–F), to long-spur petals without basal lamina (Fig. 2G–I), and finally into short-spur or slipper-shaped petals (Fig. 2J–P), all of which is contrary to the hypothesis proposed by Ying (2002).

The flower colour of *Epimedium*, including that of inner sepal, petal, anther and filament, is relatively stable and often used to identify different species of the genus. However, the flower colour varies in some *Epimedium* species, although the character is relatively stable within populations. For example, *E. acuminatum* has yellow and purple flowers, while *E. acuminatum*, *E. pubescens* and *E. sagittatum* have both yellow and green anthers (Zhang et al., 2011; Xu et al., 2019) (Fig. 2G–I, O–P). In addition, the stamens of *Epimedium* species usually have 1–2 mm long filaments. However, *E. fargesii*, *E. qingchengshanense* G. Y. Zhong & B. L. Guo and

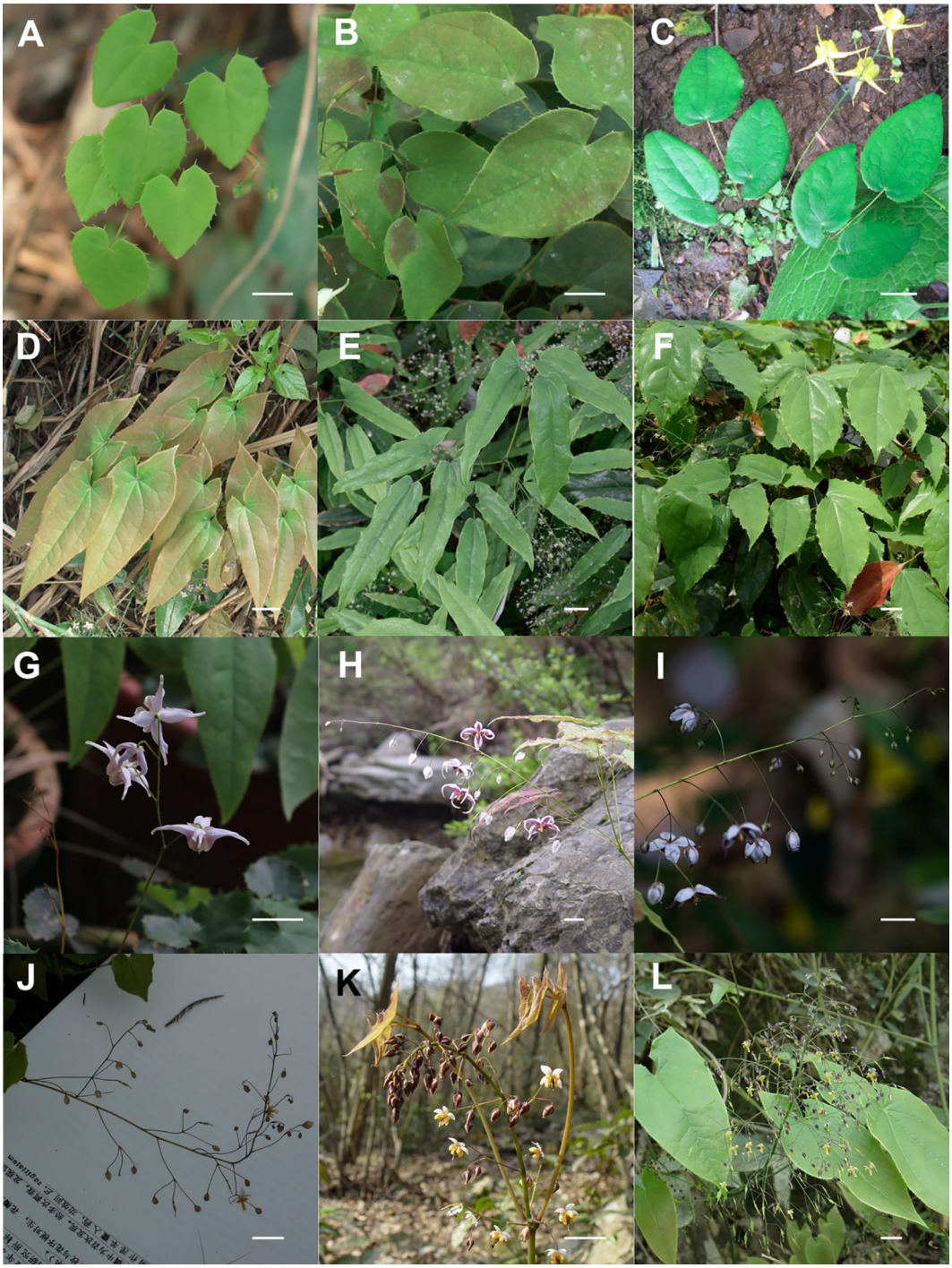

Fig. 1. Leaf shape in *E. platypetalum* (A), *E. enshiense* (B), *E. fangii* (C), *E. sagittatum* (D), *E. borealiguizhouense* (E), *E. truncatum* (F) and inflorescence of *E. pauciflorum* (G), *E. acuminatum* (H), *E. mikinorii* (I), *E. elachyphyllum* (J) and *E. sagittatum* (K–L). Scale bar = 2 cm.

E. dolichostemon have 4–5 mm long filaments, which make their stamens obviously protrude from the flowers and are a very stable and interesting taxonomic character (Fig. 2J–K).

3.6. Capsule

The morphological characters of their capsules have certain taxonomic values. For instance, *E. sagittatum*, *E. myrianthum*, *E. pubescens*, *E. stellulatum* and *E. brevicornu* have about 1 cm long capsules, while *E. acuminatum*, *E. franchetii*, *E. lishichenii* and *E. membranceum* have 2–2.5 cm long capsules. However, the fruit period of *Epimedium* is relatively short and the capsules burst and fall off when they are ripe. Therefore, many *Epimedium* herbaria have no capsule and many *Epimedium* species lack descriptions about their capsules, which affects the application of these characters in classical taxonomy of *Epimedium*.

4. Species and distribution of *Epimedium*

Epimedium is the largest herbaceous genus of Berberidaceae. In the present paper, we reviewed *Epimedium* and preliminarily

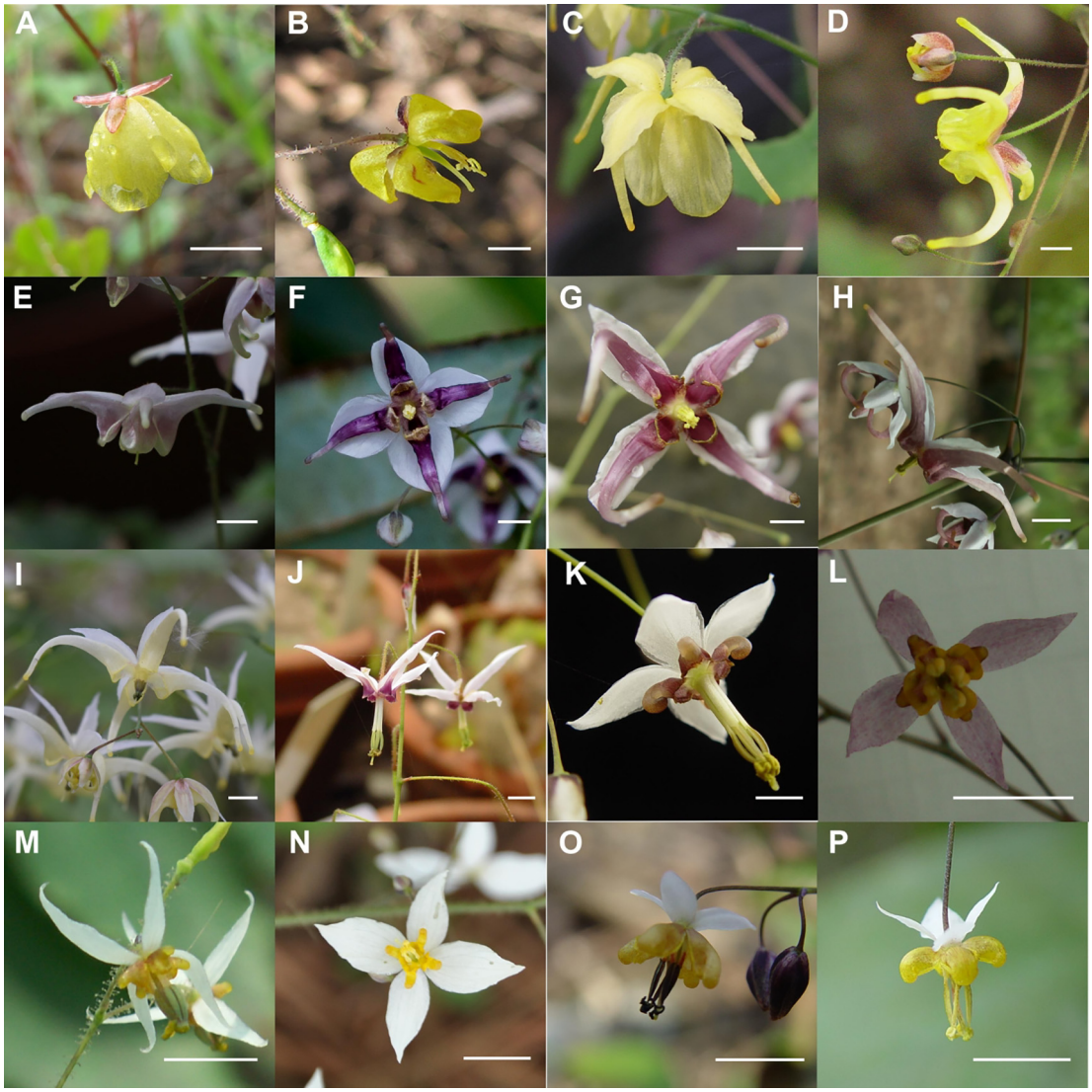

Fig. 2. Flowers of *E. campanulatum* (A), *E. reticulatum* (B), *E. flavum* (C), *E. hunanense* (D), *E. pauciflorum* (E), *E. mikinorii* (F), *E. acuminatum* (G–I), *E. fargesii* (J), *E. dolichostemon* (K), *E. elachyphyllum* (L), *E. pubescens* (M), *E. stellulatum* (N), *E. sagittatum* (O–P). Scale bar = 5 mm.

recognised that the genus comprises about 62 species (Table 2). As an Old World genus, *Epimedium* is distributed disjunctively and very unevenly in woodlands or scrubs in the Mediterranean region, western Asia and eastern Asia (Fig. 3). According to Stearn's system (2002), subg. *Rhizophyllum* consists of *E. perralderianum* endemic to Algeria and *E. pinnatum* endemic to Caucasia. Subgenus *Epimedium* comprises four sections. Section *Epimedium* is with *E. alpinum* in the Alps and the Balkan region and *E. pubigerum* from Caucasia. Section *Polyphyllon* contains only one species, *E. elatum*, which is limited to western Himalaya. Section *Macroceras* includes six species distributed in Japan, Korea, north-eastern China and Far Eastern Russia. Section *Diphyllon* possesses about 51 species in central-southeastern China.

China is the diversity centre and distribution centre for *Epimedium*, probably being the origin of the genus and the only place where the evolution of *Epimedium* has continued without interruption and where new species may yet be discovered (Stearn, 2002). In this paper, we preliminarily recognised that there are about 52 species of the genus in China (Table 2) and proposed the newest key to Chinese *Epimedium*. Among the 52 Chinese *Epimedium* species, *E. sagittatum*, *E. pubescens*, *E. brevicornu*, *E. koreanum* and *E. wushanense* were included in *Chinese Pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020) within which the former four species are designated as the origin species of *Epimedii Folium* while *E. wushanense* is designated as the origin species of *Epimedii Folium Wushanensis*. Four other *Epimedium* species, *E. acuminatum*, *E. myrianthum*, *E. coactum* and *E. leptorrhizum*, were included in *Quality Standard of Traditional Chinese Medicine and Ethnic Medicine in Guizhou Province* (Guizhou Drug Administration, 2003). Except for *E. koreanum* belonging to sect. *Macroceras* and distributed in Jilin and Liaoning of China, Japan and Korea, the other 51 *Epimedium* species constitute sect. *Diphyllum,* are all endemic to China and are distributed in the region south of the Qingling Mountains and Huaihe River, north of Xijiang River, east of East China and west of the Hengduan Mountians (24°–36°N, 98°–122°E) (Ying, 2002) (Fig. 4). The diversity of Chinese *Epimedium* species is most abundant in eastern Sichuan, western Hubei, Chongqing, north-eastern Guizhou and north-western Hunan.

5. Phylogenetic research of *Epimedium*

Epimedium is an endemic genus to the Old World, and the closest relative of the genus is *Vancouveria* native to western North America (Stearn, 2002). Both *Epimedium* and *Vancouveria* are

Table 2
Species list of *Epimedium*, including Latin name, distribution region and journal and year in which each species was published.

No.	Latin names	Distribution regions	Journals	Year
Subgen. *Epimedium*				
Sect. *Diphyllon* (Kom.) Stearn (all endemic to China)				
Ser. *Campanulatae* Stearn				
1	*E. campanulatum* Ogisui	Sichuan	Kew Bull.	1996
2	*E. platypetalum* K. I. Mey	Sichuan, Shaanxi	Repert. Spec. Nov. Regni Veg. Beih.	1922
3	*E. ecalcaratum* G. Y. Zhong	Sichuan	Acta Phytotax. Sin.	1991
4	*E. reticulatum* C. Y. Yu	Sichuan	Acta Phytotax. Sin.	1987
Ser. *Davidianae* Stearn				
5	*E. davidii* Franch.	Sichuan	Nouv. Arch. Mus. Hist. Nat.	1886
6	*E. fangii* Stearn	Sichuan	Curtis's Bot. Mag.	1995
7	*E. flavum* Stearn	Sichuan	Curtis's Bot. Mag.	1995
8	*E. latisepalum* Stearn	Sichuan	Kew Mag.	1993
9	*E. ogisui* Stearn	Sichuan	Kew Mag.	1993
10	*E. xichangense* Y. J. Zhang	Sichuan	Phytotaxa	2016
11	*E. pauciflorum* K. C. Yen	Sichuan	Acta phytotax. Sin.	1993
12	*E. shuichengense* S. Z. He	Guizhou	Acta Bot. Yunnan.	1996
13	*E. wushanense* T. S. Ying*	Chongqing, Hubei	Acta Phytotax. Sin.	1975
14	*E. epsteinii* Stearn	Hunan	Kew Bull.	1997
15	*E. hunanense* (Hand.-Mazz.) Hand.-Mazz.	Hunan, Guangxi	Symb. Sin.	1931
16	*E. shennongjiaense* Y. J. Zhang & J. Q. Li	Hubei	Novon	2009
17	*E. stearnii* Ogisu & Rix	Hubei	Bot. Mag.	2011
18	*E. mikinorii* Stearn	Hubei	Kew Bull.	1998
19	*E. pseudowushanense* B. L. Guo	Guangxi, Guizhou	Acta Phytotax. Sin.	2007
Ser. *Dolichocerae* Stearn				
20	*E. elongatum* Kom.	Sichuan	Trudy Imp. S.-Peterburgsk. Bot. Sada	1908
21	*E. membranaceum* K. I. Mey	Sichuan, Yunnan	Repert. Spec. Nov. Regni Veg. Beih.	1922
22	*E. zhaotongense* G. W. Hu	Yunnan	Phytotaxa	2017
23	*E. acuminatum* Franch.#	Chongqing, Guizhou, Sichuan, Yunnan	Bull. Soc. Bot. France	1886
24	*E. jinchengshanense* Y. J. Zhang & J. Q. Li	Sichuan	Phytotaxa	2014
25	*E. ilicifolium* Stearn	Chongqing, Shaanxi	Kew Bull.	1998
26	*E. glandulosopilosum* H. R. Liang	Chongqing	Acta Phytotax. Sin.	1990
27	*E. leptorrhizum* Stearn#	Chongqing, Guangdong, Guangxi, Guizhou, Hubei, Hunan	J. Bot.	1933
28	*E. sutchuenense* Franch.	Chongqing, Guizhou, Hubei	J. Bot. (Morot)	1894
29	*E. zhushanense* K. F. Wu & S. X. Qian	Hubei	Acta Phytotax. Sin.	1985
30	*E. enshiense* B. L. Guo & P. G. Xiao	Hubei	Acta Phytotax. Sin.	1993
31	*E. franchetii* Stearn	Hubei	Kew Bull.	1996
32	*E. baojingense* Q. L. Chen & B. M. Yang	Guizhou, Hunan	Acta Phytotax. Sin.	1982
33	*E. lishihchenii* Stearn	Jiangxi	Kew Bull.	1997
34	*E. yinjiangense* M. Y. Sheng & X. J. Tian	Guizhou	Novon	2011
Ser. *Brachycerae* Stearn				
35	*E. fargesii* Franch.	Chongqing	J. Bot. (Morot)	1894
36	*E. qingchengshanense* G. Y. Zhong & B. L. Guo	Sichuan	Acta Phytotax. Sin.	2007
37	*E. dolichostemon* Stearn	Guizhou, Chongqing, Hubei	Kew Bull.	1990
38	*E. elachyphyllum* Stearn	Guizhou	Guihaia	1994
39	*E. muhuangense* S. Z. He & Y. Y. Wang	Guizhou	Phytotaxa	2017
40	*E. truncatum* H. R. Liang	Hunan	Acta Phytotax. Sin.	1990
41	*E. pubescens* Maxim.*	Chongqing, Gansu, Shaanxi, Sichuan	Bull. Acad. Imp. Sci. Saint-Pétersbourg	1877
42	*E. stellulatum* Stearn	Hubei	Kew Bull.	1993
43	*E. brevicornu* Maxim.*	Gansu, Henan, Ningxia, Qinghai, Shanxi, Shaanxi, Sichuan	Trudy Imp. S.-Peterburgsk. Bot. Sada	1889
44	*E. sagittatum* (Siebold & Zuccarini) Maxim.*	Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangxi, Zhejiang	Mel. Biol. ix.	1876
45	*E. myrianthum* Stearn#	Hunan	Kew Bull.	1998
46	*E. coactum* H. R. Liang & W. M. Yan#	Guizhou	Acta Phytotax. Sin.	1990
47	*E. borealiguizhouense* S. Z. He & Y. K. Yang	Chongqing, Guizhou, Hubei, Hunan	J. Pl. Resourc. Environ.	1993
48	*E. multiflorum* T. S. Ying	Guizhou	Fl. Reipubl. Popularis Sin.	2001
49	*E. jingzhouense* G. H. Xia & G. Y. Li	Hunan	Nordic J. Bot.	2009
50	*E. pudingense* S. Z. He, Y. Y. Wang & B. L. Guo	Guizhou	Ann. Bot. Fenn.	2010
51	*E. tianmenshanensis* T. Deng, D. G. Zhang & H. Sun	Hunan	Phytotaxa	2015
Sect. *Macroceras* C. Morren & Decne (from Japan, Korea, Northeast China, Far Eastern Russia)				
52	*E. koreanum* Nakai*	Japan, Korea, China (Jilin, Liaoning) (dispute)	Fl. Sylv. Kor.	1936
53	*E. grandiflorum* C. Morren	Japan, Korea, China (Jinlin, Liaoning) (dispute)	Hort. Belge	1834
54	*E. sempervirens* Nakai ex F. Maek.	Japan (Honshu)	Bot. Mag. (Tokyo)	1932
55	*E. macrosepalum* Stearn	Russia (Far Eastern Area)	J. Linn. Soc., Bot.	1938
56	*E. trifoliolatobinatum* (Koidz.) Koidz.	Japan (Shikoku)	Acta Phytotax. Geobot.	1939
57	*E. diphyllum* G. Lodd.	Japan (Kyushu)	Bot. Cab.	1832
Sect. *Polyphyllon* (Kom.) Stearn (endemic to Kashimir)				

Table 2 (*continued*)

No.	Latin names	Distribution regions	Journals	Year
58	*E. elatum C. Morren & Decne.*	Kashimir	Fl. Sylv. Kor.	1936
Sect. *Epimedium* (from Europe, Caucasus and North Africa)				
59	*E. alpinum* L.	Alps and mountain ranges of the Balkan peninsula	Sp. Pl.	1753
60	*E. pubigerum* C. Morren & Decne.	Caucasia	Ann. Sci. Nat., Bot.	1834
Subgen. *Rhizophyllum* (Fisch. & C. A. Mey.) Stearn (from Caucasus and North Africa)				
61	*E. pinnatum* Fisch.	Caucasia	Syst. Nat. [Candolle]	1821
62	*E. perralderianum* Coss.	Algeria	Bull. Soc. Bot. France	1862

Note: Species with *are included in *Chinese Pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020) and Species with # are included in *Quality Standard of Traditional Chinese Medicine and Ethnic Medicine in Guizhou Province* (Guizhou Drug Administration, 2003).

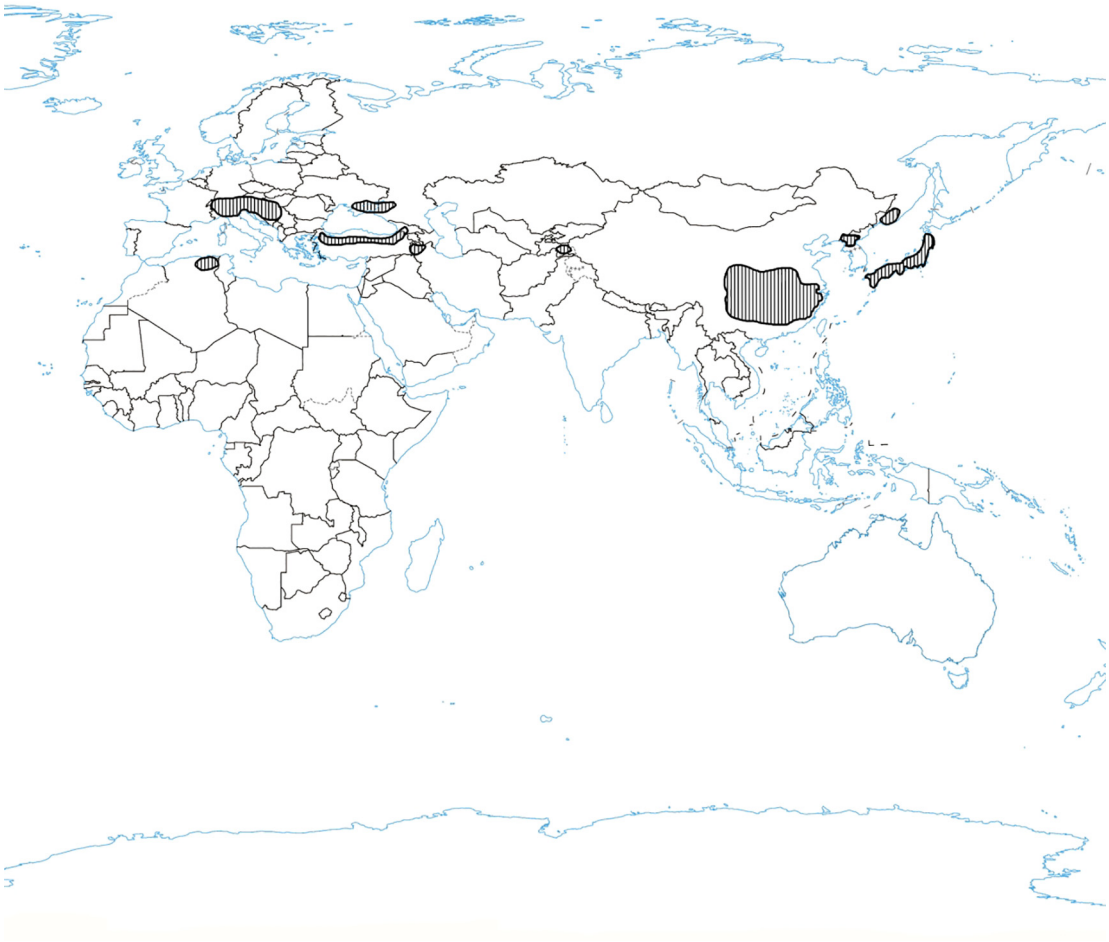

Fig. 3. Global distribution of *Epimedium*.

perennial herbs, and usually have compound leaves with a cordate base and clawed petals. In the taxonomic history of *Epimedium*, *Vancouveria* had once been treated as one section or subgenus of *Epimedium* by Baillon (1862), Franchet (1886) and Komarov (1908). However, *Epimedium* has dimerous flowers while *Vancouveira* has trimerous flowers. Since Stearn (1938) removed subg. *Vancouveria* from *Epimedium* and recognised it as an independent genus, the genus *Vancouveria* has been accepted by taxonomists (Stearn, 2002; Ying, 2002; Kim et al., 2004; Wang et al., 2007). Based on molecular data, the monophyly of *Vancoveria*, like that of *Epimedium*, has been verified and the close sister relationship of the two genera has been verified (Kim & Jansen, 1996, 1998; Kim et al., 2004; Sun et al., 2005; Zhang et al., 2007; De Smet et al., 2012; Zhang et al., 2014; Sun et al., 2018).

Morren and Decaisne (1834) classified *Epimedium* into two sections, and the taxonomic system of the genus has been revised mainly based on morphological characters (Fischer von & Meyer, 1846; Baillon, 1862; Franchet, 1886; Stearn, 1938, 2002). The updated system of *Epimedium* was established by Stearn (2002), which divided the genus into two subgenera, four sections and four series. In contrast with previous classification systems, Stearn's system (2002) is relatively reasonable and has been used by researchers. However, the system was only based on leaf and flower morphology, C-banding of chromosomes and geographical distribution. The data of C-banding of chromosomes (Tanaka & Takahashi, 1981; Takahashi, 1989) did not cover all the taxa of the system, as only four Chinese species from ser. *Dolichocerae* and ser. *Brachycerae* were studied and the other two series of sect.

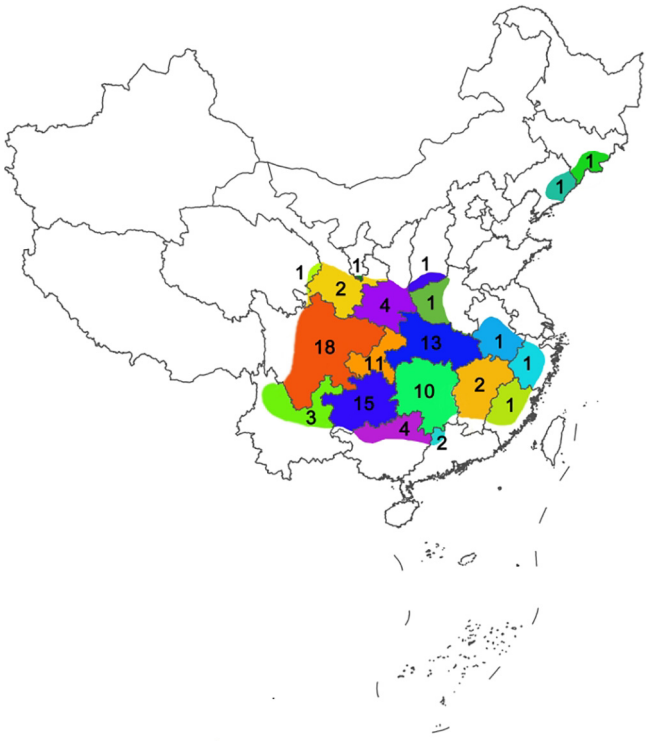

Fig. 4. Distribution of *Epimedium* in China. Figures indicate the number of *Epimedium* species in each province.

Diphyllon of China and sect. *Polyphyllon* were not studied. Furthermore, the results only demonstrated that the chromosome C-banding of *Epimedium* from the Mediterranean region, China and Japan could be divided into three types, which indicated no differences between the two taxa from the Mediterranean region, sect. *Epimedium* and subg. *Rhizophyllum*. Therefore, further research is necessary to investigate the scientific nature of Stearn's (2002) system.

In order to achieve a natural classification system of *Epimedium*, researchers conducted phylogenetic studies on the genus using pollen exine ornamentation (Guo, Xiao, & He, 1998), flavonoids (Guo, Pei, & Xiao, 2008) and molecular markers (Nakai, Shoyama, & Shiraishi, 1996; Guo 1999; Sun et al., 2005; Zhang et al., 2007; De Smet et al., 2012; Zhang et al., 2014b, 2016a). In Stearn's (2002) system of *Epimedium*, subg. *Rhizophyllum* and four sections of subg. *Epimedium* have, respectively, their relatively unique distribution regions. Molecular phylogenetic analyses, based on internal transcribed spacer (ITS), *trnK-matK*, *atpB-rbcL* spacer sequences, random amplified polymorphic DNA (RAPD), PCR-restriction fragment length polymorphism (RFLP) and amplified fragment length polymorphisms (AFLPs), consistently supported subg. *Rhizophyllum* and four sections of subg. *Epimedium* as five distinct clades (Nakai, Shoyama, & Shiraishi, 1996; Guo 1999; Sun et al., 2005; Zhang et al., 2007; De Smet et al., 2012; Zhang et al., 2014b). However, the two subgenera were not well supported and the relationships among five clades were unresolved except for sect. *Epimedium* as the sister group to sect. *Macroceras*. For Chinese sect. *Diphyllon*, although Stearn (2002) divided the section into four series related to flower characters, taxonomic studies only showed some correlation with flower characters based on pollen exine ornamentation (Guo, Xiao, & He, 1998) and flavonoids (Guo, Pei, & Xiao, 2008). Phylogenetic analysis based on AFLP data (Zhang et al., 2014b) divided the section into five well-supported clades related to flower morphology except that five species were either isolated or formed a general polytomy. However, the phylogenetic relationships among the five major clades of sect. *Diphyllon* were not well-resolved and all the species from the same series did not cluster into one clade. Phylogenetic trees were also constructed based on *Epimedium* chloroplast genome sequences (Zhang et al., 2016a; Guo et al., 2019). The results showed that *E. lishihchenii* of ser. *Brachycerae* clustered with *E. pseudowushanense* of ser. *Dolichocerae*, and not with *E. acuminatum* of ser. *Brachycerae*. This coincided with the phylogenetic studies based on AFLPs (Zhang et al., 2014b).

Epimedium is a very old taxon and has disjunctive and uneven distribution in the Old World, which includes abundant morphological differentiations. According to the molecular clock approach using *rbcL* sequences, Zhang et al. (2007) inferred that *Epimedium* originated between 9.7 and 7.4 million years ago, Chinese sect. *Diphyllon* originated 0.52 to 0.4 million years ago and the diversification of Chinese sect. *Diphyllon* was probably a result of frequent range shifts in the Quaternary Period. Ying (2002) and Stearn (2002) proposed two different petal evolution routes of *Epimedium* and two different routes for leaflet number evolution of the genus. The results of phylogenetic studies, based on pollen exine ornamentation (Guo, Xiao, & He, 1998), flavonoids (Guo, Pei, & Xiao, 2008) and AFLPs (Zhang et al., 2014b), only supported Stearn's (2002) hypothesis on the petal evolution routes to some extent. However, the flower evolution route of *Epimedium*, as well as the foliar evolution of the genus, is unclear. Furthermore, because a natural phylogenetic reconstruction of *Epimedium* is lacking, the area of origin of the genus, as well as its ways of migration and dispersal in the North Temperate Zone, have not been well explained.

In general, although researchers carried out phylogenetic studies on *Epimedium*, a natural taxonomic system of *Epimedium* has not been achieved yet. The taxonomic system of *Epimedum* needs further improvement by finding additional evidence, particularly for the classification of subgenera, sections and series of the genus. Further exploration on its origin, evolution, migration and dispersal in the Old World is needed based on phylogenetic construction and biogeographical theory and methods.

6. Taxonomic research of Chinese *Epimedium*

6.1. Progress in taxonomy of Chinese Epimedium

Since 1975 about 45 *Epimedium* species endemic to China have been published (Ying, 1975, 2001; Ying, Boufford, & Brach, 2011; Zhang et al., 2016b; Wang, Xu, & He, 2017; Wei et al., 2017). These new species have greatly enriched our understanding of Chinese *Epimedium*. However, with so many new species published in such a short period of time, it is inevitable that some taxonomic problems of Chinese *Epimedium* appear. Researchers have conducted a series of taxonomic revisions on Chinese *Epimedium* based on classical classification and molecular phylogenetic studies (He, Guo, & Wang, 2003; Zhang et al., 2011, 2014a, 2014b, 2015a, 2015b; Xu et al., 2016). Here we review the following five main revisions of Chinese *Epimedium*.

6.1.1. Taxonomic revision of unifoliolate Chinese Epimedium

Six Chinese *Epimedium* species, *E. simplicifolium* T. S. Ying, *E. baojingense*, *E. zhushanense* K. F. Wu & S. X. Qian, *E. glandulosopilosum* H. R. Liang, *E. elachyphyllum* and *E. muhuangense* S. Z. He & Y. Y. Wang are the only species of the genus once described with unifoliolate leaves (Stearn, 2002; Wang, Xu, & He, 2017). Zhang et al. (2011) reviewed the former five species, treated *E. simplicifolium* as the synonym of *E. acuminatum* and proposed that *E. baojingense*, *E. zhushanense* and *E. glandulosopilosum* have predominantly trifoliolate and occasionally unifoliolate leaves. Furthermore, because the protologue of *E. baojingense* lacks the descriptions about flow-

ers and fruits (Chen & Yang, 1982), Zhang et al. (2011) supplemented these descriptions and proposed that the species is usually with racemose and sometimes paniculate with glandular hairs, instead of being racemose with dark-yellow puberulous hairs in its protologue. Similarly, some morphological characters of *E. zhushanense*, *E. glandulosopilosum* and *E. elachyphyllum*, such as inflorescence and flower character, were also revised by Zhang et al. (2011). In addition, neotypes for *E. zhushanense* and *E. glandulosopilosum* were designated because the type of the two species had been lost (Zhang et al., 2011).

All *Epimedium* plants initially have several unifoliolate euphylla after seed germination. The *Epimedium* species with trifoliolate leaves are occasionally found with cauline unifoliolate leaves. *E. elachyphyllum* and *E. muhuangense* are the only two species in *Epimedium* which have leaves consisting of a single leaflet. Both species occur in two nearing counties of Tongren, Guizhou province, China and have very similar morphological characters. When *E. muhuangense* was published, Wang et al. (2017) described that the species could be different from *E. elachyphyllum* by its stout and short rhizomes, two opposite glabrous leaves on flowering stems and paniculate inflorescences. However, according to our field investigation on the type locality, we found that *E. elachyphyllum* occasionally has two alternate or opposite unifoliolate leaves on the flowering stem and the inflorescence is often paniculate with the lower peduncles bearing 2–5 flowers (Zhang et al., 2011). The two species are only known from the type localities and further explorations on their morphological variations as well as on their taxonomic relationships are needed.

6.1.2. Taxonomic clarification of E. wushanense species complex

Epimedii Folium Wushanensis is embodied as traditional Chinese medicinal material in *Chinese Pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020), in which *E. wushanense* is the only botanical origin of the medicinal material. However, the practical application of *Epimedii Folium Wushanensis* was very chaotic, because its active components were very different among various distribution regions (Pei, Guo, & Huang, 2008). Guo et al. (2007) proposed that *E. wushanense* was a species with similar leaf shapes and various flower characters. Furthermore, Guo et al. (2007) reported *E. pseudowushanense* which had been previously used as *E. wushanense*. However, *E. pseudowushanense* was treated as an insufficiently known species in *Flora of China* (Ying, Boufford, & Brach, 2011). Zhang et al. (2014a) studied all seven type specimens of *E. wushanense* and conducted field investigations covering all the type localities and the regions representing all morphological differentiations of the species. The results showed that *E. wushanense,* described in *Flora Reipublicae Popularis Sinicae* (Ying, 2001) and *Flora of China* (Ying, Boufford, & Brach, 2011), includes four species similar in leaflet shape: *E. wushanesne*, *E. ilicifolium*, *E. jinchengshanense* (sp. nov.) and *E. pseudowushanense* (Fig. 5). The original description of *E. wushanense* was based on the seven type specimens representing the first three of the four species, not just on the holotype. The holotype *T.P. Wang 10,757* (PE) and the two paratypes, *T.P. Wang 10,345* (PE) and *G.H. Yang 57,725* (PE), belong to one *Epimedium* species, which was therefore delimited as *E. wushanense*. Except for the paratype *P.T. Nee 37* (CDBI) identified as *E. ilicifolium*, the remaining three paratypes, *Sichuan Econ. Pl. Exped. Nan* 2 (CDBI, KUN, PE, SAU, SM), *2742* (CDBI, KUN, PE, SAU) and *5018* (KUN, PE), represent the new species, *E. jinchengshanense*. Furthermore, *Flora of China* (Ying, Boufford, & Brach, 2011) listed Guangxi and Guizhou as distribution localities of *E. wushanense*. Precisely, the so-called *E. wushanense* from Guangxi and Guizhou is *E. pseudowushanense*. In addition, Stearn (2002) classified *E. wushanense* into ser. *Dolichocerae* and *E. ilicifolium* into ser. *Davidianae*. However, the description of *E. wushanense* is that of *E. jinchengshanense* in Stearn's (2002) monograph. *E. wushanense* should be placed in ser. *Davidianae* due to its petals having long spurs with obvious basal lamina. *E. ilicifolium* has petal spurs without basal lamina and should be relocated into ser. *Dolichocerae*. *E. wushanense*, *E. jinchengshanense*, *E. ilicifolium* and *E. pseudowushanense*, can not only be easily differentiated from their corolla characters, but also have small differences in leaflet morphology. Furthermore, each of the four species have relatively independent distribution regions.

6.1.3. Revision of three Epimedium species with controversies on flower characters

Three Chinese *Epimedium* species, *E. reticulatum* C. Y. Wu ex S. Y. Bao, *E. shuichengense* S. Z. He and *E. truncatum* have been controversial on flower characters (Ying, 2001; Stearn, 2002; Guo, Pei, & Xiao, 2008; Ying, Boufford, & Brach, 2011). In the protologue, Bao (1987) described *E. reticulatum* with small flowers bearing calcariform and 1–2 mm long petals and Stearn (2002) classified it into ser. *Brachycerae*. However, the species was descried with horn-shaped and ca. 4.5 mm long petals in *Flora Reipublicae Popularis Sinicae* (Ying, 2001) and *Flora of China* (Ying, Boufford, & Brach, 2011). Guo et al. (2008) proposed that *E. reticulatum* had long-spurred petals with a close affinity to *E. membranaceum* and that it should belong to ser. *Dolichocerae*. According to a series of studies, Zhang et al. (2015a) found that all the eight sheets of the type specimens actually represent two species, *E. reticulatum* and *E. membranaceum*, which might be confused when collected. For the holotype, the main element belongs to *E. reticulatum* but lacks flowers while the materials conserved in the small paper bag of the specimen contain the flowers of *E. membranaceum*, the leaves of *E. reticulatum* and the fruits probably from both the two species. Five sheets of the seven isotypes without flowers belong to *E. reticulatum,* while the other two sheets with flowers belong to *E. membranaceum*. As researchers had been learning about the species only from these type specimens, all the previous descriptions of the flowers of *E. reticulatum* were actually based on those of *E. membranaceum*. The great flower differences, described by different researchers, may probably be caused by observing flowers of *E. membranaceum* at different developmental stages. Therefore, Zhang et al. (2015a) re-described the flower of *E. reticulatum* based on observations of the type locality and moved it to ser. *Campanulatae* according to the flower features (small and campanulate flowers, flat petal with slightly cucullate base), which was supported by molecular phylogenetic evidence (Zhang et al., 2014b). Furthermore, according to Art. 9.14 of the ICN (McNeill et al., 2012), the lectotype and isolectotypes of *E. reticulatum* were also designated. In addition, *E. shuichengense* and *E. truncatum* were also revised, *E. shuichengense* was adjusted from ser. *Campanulatae* into ser. *Davidianae* and a neotype for *E. truncatum* was designated (Zhang et al., 2015a).

6.1.4. Synonyms in Chinese Epimedium

Epimedium is an intractable taxon that has many species with great variations in morphology. As these variations are insufficiently understood, some new *Epimedium* species were published which are, in fact, synonymous with the existing species. Since 1975, six species and two varieties of Chinese *Epimedium* have been reduced to synonyms. *E. simplicifolium* and *E. chlorandrum* Stearn was treated as two synonyms of *E. acuminatum*, *E. rhizomatosum* Stearn was placed as a synonym of *E. membranceum*, *E. brachyrrhizum* Stearn as a synonym of *E. leptorrhizum*, *E. dewuense* S. Z. He, Probst & W.F. Xu as a synonym of *E. dolichostemon*, *E. lobophyllum* L. H. Liu & B. G. Li and *E. sagittatum* var. *pyramidale* (Franch.) Stearn as synonyms of *E. myrianthum*, and *E. sagittatum* var. *oblongifoliolatum* Z. Cheng as a synonym of *E. borealiguizhouense* (Ying, Boufford, & Brach, 2011; Zhang et al., 2011, 2015b; He, 2014).

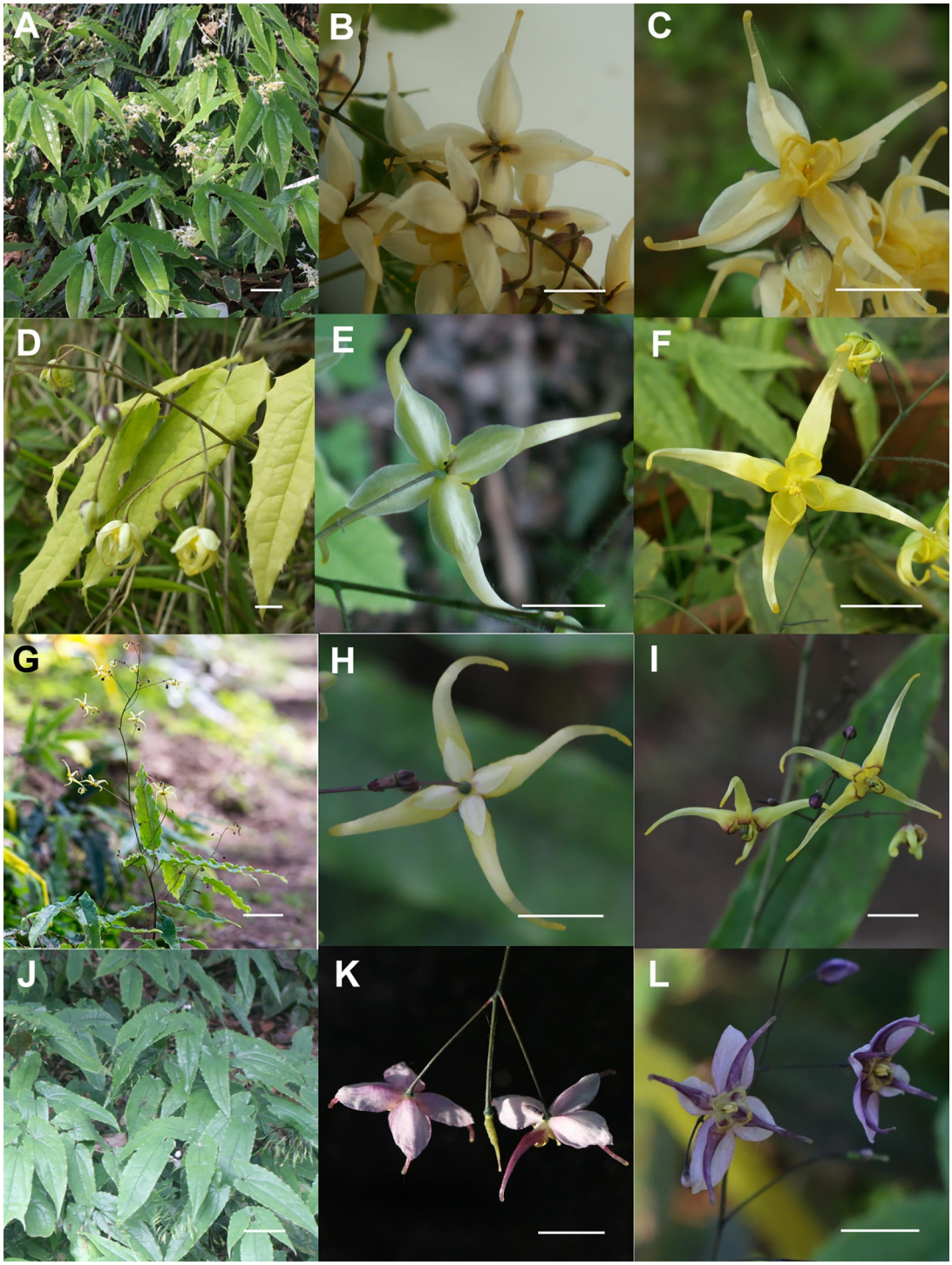

Fig. 5. Photos of *E. wushanense* (A–C), *E. ilicifolium* (D–F), *E. jinchengshanense* (G–I) and *E. pseudowushanense* (J–L). Scale bar = 5 cm in plate A, G, J, and scale bar = 1 cm in plate B, C, D, E, F, H, I, K and L.

Ying (1975) treated *E. membranceum* as a synonym of *E. davidii*, which had been accepted by *Flora Reipublicae Popolaris Sinica* (Ying, 2001) and *Flora of China* (Ying, Boufford, & Brach, 2011). However, *E. membranceum* and *E. davidii* are two different species. *E. membranceum* has leaves with three leaflets and petals without basal lamina, belonging to ser. *Dolichocerae*, while *E. davidii* has leaves with five or three leaflets and petals with obvious basal lamina, belonging to ser. *Davidianae* (Fig. 6A–F).

In addition, the above results of classical taxonomic research have been well supported by molecular phylogenetic studies except that *E. lobophyllum* and *E. sagittatum* var. *pyramidale* were not involved (Zhang et al., 2014b). For example, *E. simplicifolium* and *E. chlorandrum* were treated as two synonyms of *E. acuminatum*, and the phylogenetic tree based on AFLP data showed the three species mixedly clustered into a separate clade. Classical taxonomic studies supported *E. membranceum* and *E. davidii* as two distinct species and molecular phylogenetic studies demonstrated that *E. davidii* grouped into a cluster consisting of the species from ser. *Campanlatae* and ser. *Davidianae*, while *E. membranceum* clustered into a clade with *E. acuminatum* of ser. *Dolichoceae* (Zhang et al., 2014b).

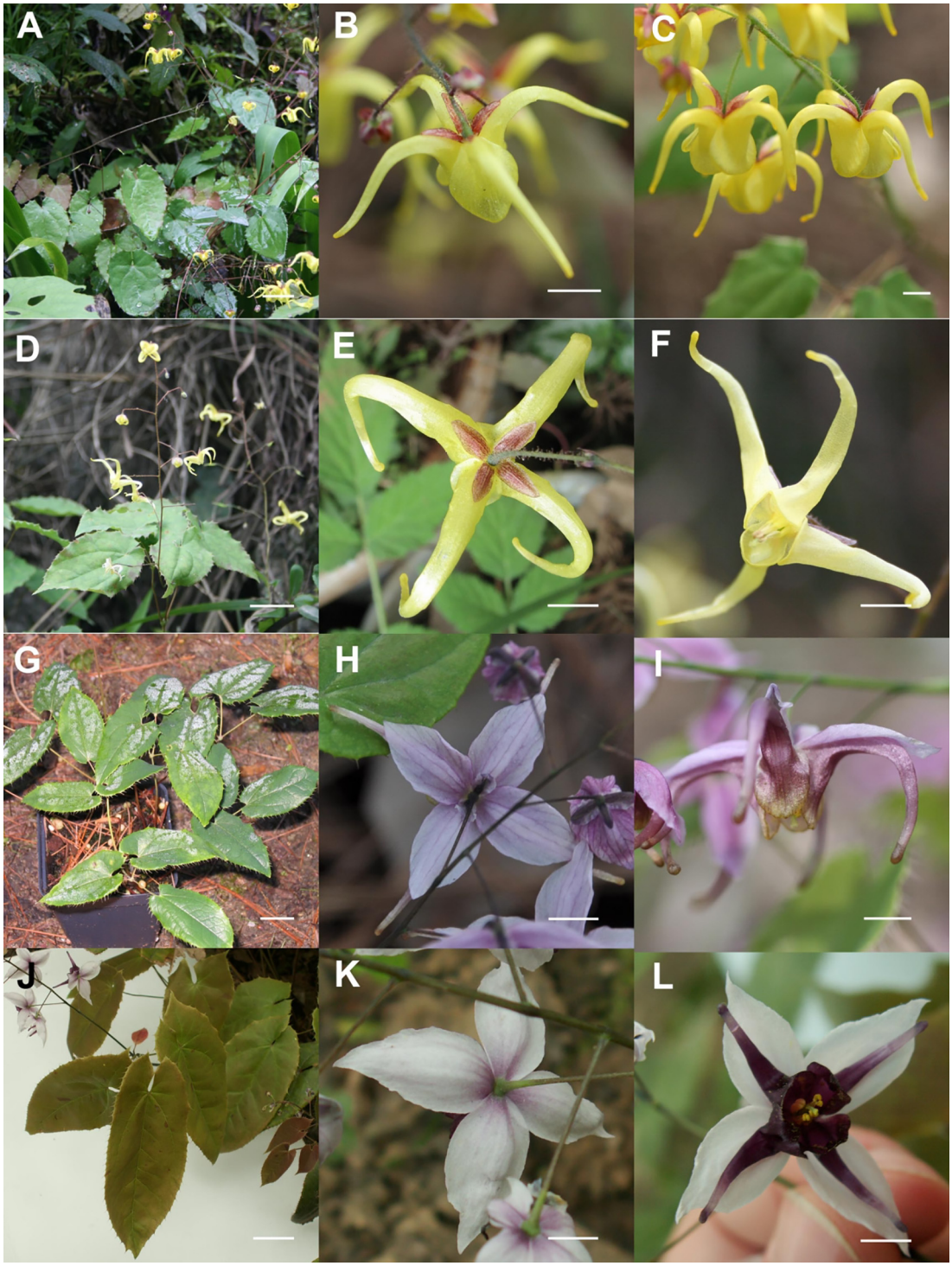

Fig. 6. Photos of *E. davidii* (A–C), *E. membranceum* (D–F), *E. epsteinii* (G–I) and *E. shennongjiaense* (J–L). Scale bar = 2 cm in plate A, D, G, J, and Scale bar = 5 mm in plate B, C, E, F, H, I, K and L.

6.1.5. Clarification of the distribution area of E. epsteinii

E. epsteinii Stearn is a species endemic to Tianping Mountain of Hunan province (Stearn, 1997). Except for the protologue, we had no other information about it and the species was treated as an insufficiently known species in *Flora of China* (Ying, Boufford, & Brach, 2011). Xu et al. (2016) reported two new distribution localities, Ruyuan county of Guangdong and Jianshi county of Hubei. We observed the living individuals of *E. epsteinii* cloned from its holotype specimen, *Darrell Probst CPC 94.0255* (K) at the garden of Mr. Darrell Probst in Hubbardston, Mass., U.S.A in 2001, investigated the species at the type localities several times from 2006 to 2020 and recognised that *E. epsteinii* is a valid species (Fig. 6G–I). Furthermore, we collected *E. leptorrhizum* at Ruyuan county of Guangdong Province which was recognised as *E. epsteinii* by Xu et al. (2016) at 2005 and 2016. As a result, we found that the species distributed in Ruyuan county of Guangdong Province should not be *E. epsteinii*, but is *E. leptorrhizum*. Although both *E. epsteinii* and *E. leptorrhizum* have elongated rhizomes, the two species differ

obviously in the leaflet and flower morphology. *E. epsteinii* has leaflets with an acuminate apex and sparse minute appressed bristle-like hairs. *E. leptorrhizum* has leaflets with a long acuminate apex, many impressed veins on the adaxial surface and bears reddish pubescence on the mid-vein and lateral veins of the abaxial surface, especially dense at the insertion of petiolules. *E. epsteinii* has petals with 5 mm tall lamina which enclose stamens and belongs to ser. *Davidianae*, while *E. leptorrhizum* has petals without basal lamina and belongs to ser. *Dolichocerae*. *E. shennongjiaense* Y. J. Zhang & J.Q. Li is a species from Hubei (Zhang & Li, 2009) (Fig. 6J–L), which is mostly similar to *E. epsteinii*, but can be distinguished by its compact rhizomes, acuminate inner sepals and its petals which are slightly shorter than or nearly as long as the inner sepals with straight spurs.

6.2. Taxonomic problems on Chinese Epimedium

Though researchers have conducted a series of taxonomic studies on Chinese *Epimedium*, the genus is a very intractable taxon and there are controversies in some Chinese species. We here conclude that the taxonomic problems of Chinese *Epimedium* need further research in the following six domains.

6.2.1. Epimedium sagittatum species complex

E. sagittatum complex is referred to as *E. sagittatum* and several of its related species. *E. sagittatum* is distributed in Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangxi, Zhejiang, while several of its related species are mainly distributed in West Hunan and Hubei, Chongqing and Guizhou (Zhang et al., 2014b). The complex is the most controversial in the taxonomy of the genus. This complex has great morphological variations within and among different species and shows unclear morphological boundaries among species (He, Guo, & Wang, 2003; Xu et al., 2013; Zhang et al., 2014b). Furthermore, in the complex, only *E. sagittatum* is one of the four original plants of *Epimedii Folium* in *Chinese pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020). However, *E. sagittatum* has great variations in bioactive components resulting in many populations not meeting the quality standards of *Epimedii Herba* in *Chinese Pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020), while many populations of its related species have high contents of bioactive components (Guo et al., 1996, 2008; Pei et al., 2007; Shen et al., 2007; Chen et al., 2015). For the further development and utilisation of Chinese *Epimedium* resources, it is very necessary to clarify the taxonomic problems which exist in the complex.

Both Stearn (2002) and He et al. (2003) treated *E. sagittatum* var. *pyramidale* as the synonym of *E. myrianthum*, which was accepted by *Flora of China* (Ying, Boufford, & Brach, 2011). He et al. (2003) also treated *E. sagittatum* var. *glabratum* T. S. Ying and *E. coactum* H. R. Liang & W. M. Yan var. *lobophyllm* H. R. Liang as synonyms of *E. myrianthum,* and published *E. sagittatum* var. *guizhouense* S. Z. He et W. M. Yan and *E. myrianthum* var. *jianheense* S. Z. He et W. M. Yan. However, *Flora of China* (Ying, Boufford, & Brach, 2011) sustained *E. sagittatum* var. *glabratum*, adjusted *E. coactum* as the synonym of *E. pubescens*, and did not accept *E. sagittatum* var. *guizhouense* and *E. myrianthum* var. *jianheense*. According to our previous morphological studies on the species complex, *E. coactum* and *E. pubescens* are obviously different species and it is inappropriate to adjust *E. coactum* as the synonym of *E. pubescens*. For *E. myrianthum* var. *jianheense*, it was not mentioned in the papers by Shunzhi He (He, Xu, & Guo, 2005; Wang, He, & Xu, 2009) and his illustrated handbook of Chinese *Epimedium* (He, 2014). Zhang et al. (2015b) adjusted *E. sagittatum* var. *oblongifoliolatum* as a synonym of *E. borealiguizhouense*. The *E. sagittatum* complex is here reviewed which consists of seven species and three varieties, *E. sagittatum*, *E. myrianthum*, *E. multifolium* T. S. Ying, *E. borealiguizhouense*, *E. pudingense* S. Z. He, Y. Y. Wang & B. L. Guo, *E. jingzhouense* G. H. Xia & G. Y. Li, *E. coactum*, *E. sagittatum* var. *glabratum*, *E. sagittatum* var. *guizhouense* and *E. coactum* var. *longtohum*.

We have analysed the intra-species variations of *E. sagittatum* on morphological, genetic and chemotypic diversity, based on a common garden experiment. The results showed that chemotype variation has a significant genetic basis and the relationships of different populations, based on morphological and genetic diversity, were related with their geographical distribution (Liang et al., 2013; Chen et al., 2015). Based on AFLP data, phylogenetic analyses were also conducted on five species and three varieties of the *E. sagittatum* species complex collected from 25 localities (Zhang et al., 2014b). The phylogenetic tree demonstrated that the 25 populations of the species complex were subdivided in a manner closely correlated with the geographical distribution. *E. multifulum*, *E. coactum* and *E. coactum* var. *longtoutum* were embedded in different populations of *E. sagittatum*, while *E. sagittatum* var. *glabratum* is more closely related with *E. myrianthum* and *E. borealiguizhouense*, and not with the original variant of *E. sagittatum*. It is urgent to achieve a scientific taxonomic treatment of *E. sagittatum* species complex.

6.2.2. Epimedium pubescens species complex

E. pubescens is one of the four original plants of *Epimedii Folium* in *Chinese pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020). In morphology, *E. pubescens* is very similar to *E. stellulatum* Stearn which was not included in *Chinese pharmacopoeia*. The two species flower earlier in Chinese *Epimedium* and their white small flowers appear beautiful and chic in early spring. *E. pubescens* has a relatively wide distribution mainly in the Sichuan Basin and its surrounding mountains, northwestern Chongqing, southern Shaanxi and southernmost Gansu (Zhang, 2009; Liu et al., 2017b). *E. stellulatum* is only recorded in Fangxian, Shiyan, Yunxi and Zhushan of Hubei province (Zhang, 2009). Liu et al. (2017b) analysed the genetic diversity and indumentum type on the abaxial surface of leaflets from 14 populations of *E. pubescens* and one population of *E. stellulatum*. Based on the ISSR marker, the UPGMA tree showed that the two species did not form two monophyletic clusters with the only one population of *E. stellulatum* being embedded in the 14 populations of *E. pubescens*. Furthermore, the indumentum type of *E. stellulatum* was the same as that of *E. pubescens* from Nanzheng of Shaanxi province. As a result, Liu et al. (2017b) proposed that *E. stellulatum* should not be an independent species, but a synonym or a variety of *E. pubescens*. Zhi et al. (2018) studied the indumentum type on the abaxial surface of leaflet of *E. pubescens* and *E. stellulatum* based on a more comprehensive sample collection, and also proposed that *E. stellulatum* should be an infra-specific taxon of *E. pubescens*. Along with further studies on the *E. pubescens* species complex, a more scientific relationship of the two species and a more natural taxonomic treatment on the species complex can be achieved.

6.2.3. Epimedium franchetii species complex

The *E. franchetii* species complex was proposed by Gao (2011), who considered that the complex should consist of *E. franchetii*, *E. baojingense*, *E. zhushanense* and *E. lishichenii*. Liu et al. (2016) conducted morphological analyses on the nine populations of the species complex in the field and observed some morphological transitional populations between *E. franchetii*, *E. lishichenii* and *E. baojingense*. Therefore, Liu et al. (2016) proposed that *E. zhushanense* was an independent species and should be removed from the *E. franchetii* complex, *E. baojingense* should be treated as *E. franchetii* var. *baojingense* (ecological race) while *E. lishihchenii* should be treated as *E. franchetii* ssp. *lishihchenii* (geographical race). However, *E. franchetii* was published in 1996, *E. lishichenii* in 1997 and *E.*

baojingense in 1982 (Chen & Yang, 1982; Stearn, 1996, 1997). Because *E. baojingense* was published earlier than the other two species, it was invalid to treat *E. baojingense* and *E. lishichenii* as the infra-species taxa of *E. franchetii* according to Art. 11.4 of the ICN (Turland et al., 2018). Among the species complex, *E. zhushanense* is relatively easily distinguishable from the above three species on the basis of flower characters: *E. zhushanense* has purple flowers and a relatively higher length ratio of the internal sepals to the petals, while the other three species usually have yellow flowers except that *E. franchetii* was reported with a pale pink flower population (Gao, 2011). However, Gao (2011) also found that one population of *E. zhushanense* has the same indumentum as *E. baojingense*. For achieving a more natural taxonomic treatment of the species complex, specimens deposited in main herbaria should be systematically analysed and more comprehensive field investigations are needed in future research.

6.2.4. Epimedium platypetalum and E. campanulatum

Series *Campanulatae* bears campanulate and small flowers with petals being flat or having a slight nectarial swelling at the base. Stearn (2002) proposed that ser. *Campanulatae* might be the most primitive in the flower evolution of *Epimedium*. The series comprises of four species, *E. platypetalum*, *E. campanulatum* Ogisu, *E. ecalacaratum* G. Y. Zhong and *E. reticulatum* (Stearn, 2002; Zhang et al., 2015a). All the four *Epimedium* species are mainly distributed in Sichuan province but one new distribution of *E. platypetalum* was reported in Shanxi province (Lu et al., 1989). Among the four species, *E. reticulatum* and *E. ecalcaratum* have petals with a slightly cucullate base, while the whole petals of *E. platypetalum* and *E. campanulatum* are flat. Furthermore, *E. reticulatum* and *E. ecalcaratum* are relatively distinctive species, and *E. reticulatum* can be easily distinguished from *E. ecalcaratum* by its thick leathery leaflets with conspicuous reticulate veins on both surfaces and much smaller flowers.

E. platypetalum and *E. campanulatum* are most closely related to each other and have some taxonomic controversies. Moreover, *E. campanulatum* has been listed as an insufficiently known species in *Flora of China* (Ying, Boufford, & Brach, 2011). Liu et al. (2017a) detailedly compared the living individuals of *E. platypetalum* from Nanzhen of Shaanxi province and those of *E. campanulatum* from Dujiangyan of Sichuan province, China. The two populations can be differentiated in terms of rhizomes, the leaf number of flower stems and petals. However, the key problem is that we cannot well understand the two species. Firstly, for *E. platypetalum*, except for the type specimen (*Limpricht 1386* (WRSLE, WU)) and one collection from 1993 (*Ogisu 93,085* (K)) (Ogisu 1995; Stearn 2002), no other collection was attained from the type locality, Wenchuan county of Sichuan province. Liu et al., (2017a) cited a specimen (*S.Y. Chen 5210* (NAS)) as *E. platypetalum* which was collected from Maoxian, another county near the type locality of Wenchuan. However, we observed the other sheets of the specimen deposited in SZ and SM, and recognised that the specimen should belong to *E. pauciflorum* which has long spur petals with an obvious basal lamina. Except for the type locality, we knew the species only from its other two distribution localities far away from the type locality, Nanjiang of northeastern Sichuan and Nanzheng of southwestern Shaanxi (Lu et al., 1989; Liu, Shi, & Xu, 2016). Therefore, the morphological characters of *E. platypetalum* are not sufficiently researched as well as our understanding of the species at the type locality. Secondly, we knew *E. campanulatum* only from the type locality, Dujiangyan, Sichuan, near the type locality of *E. platypetalum*. Stearn (2002) proposed that *E. campanulatum* differed from *E. platypetalum* in having narrowly ovate leaflets, while those of *E. platypetalum* are broadly ovate or almost orbicular.

In general, it is difficult to compare *E. platypetalum* and *E. campanulatum* because of a lack of sufficient investigations and collections. For attaining a scientific taxonomy treatment of the two species, the following problems need to be addressed: 1) What are the standard morphological characters of *E. platypetalum* at the type localities? 2) The two distribution localities of *E. platypetalum*, Nanjiang and Nanzheng, are much farther from its type locality, while the two type localities of *E. platypetalum* and *E. campanulatum* are very near. What is the difference between the two populations of *E. platypetalum* and standard *E. platypetalum* and *E. campanulatum* at their type localities? 3) What are the actual distribution areas and morphological variations of *E. platypetalum* and *E. campanulatum*? What are the differences between *E. platypetalum* and *E. campanulatum*?

6.2.5. Epimedium koreanum and E. grandiflorum

E. koreanum is one original species of *Epimedii Folium* in *Chinese pharmacopoeia* (Chinese Pharmacopoeia Commission, 2020). *E. koreanum* is very similar to *E. grandiflorum* C. Morren and there are controversies on the taxonomic treatment of the two species (Stearn, 2002). In *Flora of China*, *E. koreanum* was recorded in Anhui, Jilin, Liaoning and Zhejiang of China, Japan and North Korea (Ying, Boufford, & Brach, 2011). According to the specimen examination and field investigation, we found that *E. koreanum* is only distributed in Jilin and Liaoning of China and has no distribution in Anhui and Zhejiang of China. Furthermore, it is reported that *E. koreanum* has been also distributed in South Korea (Flora of Korea Editorial Committee 2008; Lee et al., 2015).

In Stearn's (2002) monograph about *Epimedium*, *E. koreanum* was described with distribution in Korea, while *E. grandiflorum* was described with distribution in Japan, North Korea and Northeast China which was recognised as *E. koreanum* in *Flora of China* (Ying, Boufford, & Brach, 2011). *E. koreanum* was recognised with elongated rhizome and yellow flowers, while *E. grandiflorum* was recognised with compact rhizome and white, pale yellow, deep rose, red–purple or violet flowers (Stearn, 2002). However, through specimen examination we found that *E. grandiflorum* in North Korea and Northeast China possesses elongated rhizomes. Furthermore, *E. grandiflorum* are usually with white, pale yellow or yellow flowers in the above two regions. Except that *E. grandiflorum* bears deep rose, red–purple or violet flowers in Japan, it is difficult to find a stable distinguishing feature between *E. koreanum* and *E. grandiflorum*.

Flora of China (Ying, Boufford, & Brach, 2011) and *Flora of Korea* (Flora of Korea Editorial Committee, 2008) only described *E. koreanum*, in both of which the distribution of *E. koreanum* covered that of *E. grandiflorum*. However, *E. koreanum* was treated as a variant of *E. grandiflorum*, var. *koreanum* (Nakai) K. Suzuki in *Flora of Japan* (Suzuki, 1995). Furthermore, Stearn (2002) proposed that *E. grandiflorum* included three formaes, forma *grandiflorum*, forma *flavescens* Stearn and forma *violaceum* (C.Morren) Stearn. *Flora of Japan* (Suzuki et al., 1995) described that *E. grandiflorum* was composed of three varieties, var. *grandiflorum*, var. *koreanum* and var. *thunbergianum* (Miq.) Nakai. The definition and taxonomy of *E. koreanum* and *E. grandiflorum* and the infra-species taxa of *E. grandiflorum* are often confused. In order to achieve a more natural taxonomic revision on *E. grandiflorum* and *E. koreanum*, it is necessary to have comprehensive specimen examinations and field investigations of the two species in all distribution regions.

6.2.6. Other taxonomic problems in Chinese Epimedium

China has the most abundant species of *Epimedium* among which about 45 species and three varieties had been published since 1975. Although *Epimedium* species are usually endemic with relatively narrow distribution, the recognition of some Chinese species of the genus is obviously insufficient. Therefore, further investigation on their distribution range and morphological variation is needed. For instance, some newly published species are only

known from their type locality. Some sister species, such as *E. qingchengshan* and *E. fargesii*, *E. elachyphyllum* and *E. muhuangense* S. Z. He & Y. Y. Wang, need further investigation to clarify their relationships. On the other hand, *Epimedium* species are distributed in remote mountainous areas, so it is very hard to investigate these lovely plants. There are still some regions in China where investigations of *Epimedium* are insufficient to some extent, such as eastern China and western Sichuan. In order to better explore and utilize *Epimedium* plants, these taxonomic problems of Chinese *Epimedium* should be resolved.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chmed.2021.12.001.

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