New taxa of *Berberis* (Berberidaceae) with greenish flowers from a biodiversity hotspot in Sichuan Province, China

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**Abstract**

A new species, *Berberis viridiflora* X. H. Li, and a new variety, *Berberis sanguinea* Franch. var. *viridisepala* X. H. Li, L. C. Zhang & W. H. Li are described and illustrated from Baoxing County, a biodiversity hotspot located on the eastern edge of Hengduan Mountains in Sichuan Province, Southwest China. Both new taxa resemble *B. sanguinea* Franch. var. *sanguinea*, but *B. viridiflora* differs by the greenish flowers, and the petals being truncate, obtuse, or undulate at apex; while *B. sanguinea* var. *viridisepala* differs by the greenish or yellowish green flowers. Morphological features of the pollen grains of *B. sanguinea* and the two new taxa are revealed by scanning electron microscope. *B. sanguinea* var. *sanguinea* displays obvious similarities with a sympatric congener, *Berberis multiflora* T. S. Ying in the morphology of flowers, stems and leaves, especially its ovule number varies greatly from 2 to 9, thus, *B. multiflora* characterized by the 5-ovuled ovary is reduced to a synonymy of *B. sanguinea* var. *sanguinea*. On the basis of field surveys and study of herbarium specimens, a total of 16 species and varieties of *Berberis* are recorded from Baoxing County, and a key is provided. Among the 16 taxa, most phenotypic variations in Chinese *Berberis* can be displayed, including the habit of plants, most morphological variations of stems, branches and leaves, all types of inflorescences, all color types of flowers, and nearly all types of the shape and color of fruits. Baoxing County and its adjacent Sichuan Giant Panda Sanctuaries possibly constitute an active diversification center of *Berberis* in eastern Hengduan Mountains of China.

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1. Introduction

Berberidaceae has the greatest center of diversity in China (Axelrod et al., 1996). *Berberis* L. is the largest genus of Berberidaceae comprising approximately 500 species. It holds two centers of species diversity in the world, one within Himalayas and China, and the other in South America (Ahrendt, 1961; Landrum, 1999). Many species of *Berberis* have been published basically relying on observation of the type specimens and insufficient field records in herbaria (e.g. Ahrendt, 1961; Schneider, 1908; Ying, 1999). Some important taxonomic characters and their variations have at times inevitably been absent or incorrectly described in their protologues (Chamberlain and Hu, 1985; Fan et al., 2015; Li and Zhang, 2014; Li et al., 2015b; Ying, 2011). In Asian *Berberis*, the color types of flowers are always recorded as yellow or sometimes greenish yellow (Adhikari et al., 2012; Ahrendt, 1961; Rao et al., 1998; Ying, 2011; Yu and Chung, 2014), with a few exceptions being purplish red or bicolored, e.g., *Berberis sanguinea* Franch., *Berberis bicolor* H. Lévêillé and *Berberis × baoxingensis* X. H. Li (Ahrendt, 1961; Li et al., 2015a; Ying, 2011). In South America, the flowers are reported as golden yellow, orange or reddish yellow (Ahrendt, 1961; Landrum, 1999). The ovaries of *Berberis* species may contain 1–15 ovules (Ahrendt, 1961; Landrum, 1999; Ying, 2011). Recent studies based on population sampling have shown that the solitary ovule is quite constant in *Berberis sublevis* W. W. Smith (Fan et al., 2015), but the number of ovules are often variable among some species (Li and Zhang, 2014; Li et al., 2015a,b). Currently, biological characteristics of many *Berberis* species have still not been sufficiently explored in China, particularly the detailed morphology of flowers and ripened fruits. Furthermore, accurate data about the current conservation status of *Berberis* species are still not well known in China.

Baoxing County is located in west-central Sichuan Province (Fig. 1), southwestern China between the Sichuan Basin and the...
in combination with study of specimens in herbaria, a total of 16 species and varieties have been recorded from Baoxing, including a new species and a new variety. Morphological characteristics of the two new taxa with greenish flowers are described and illustrated herein, and their conservation status is also discussed.

2. Materials and methods

Specimens of Berberis were examined in herbaria of BM, E, K, KUN and PE. Images of Berberis specimens were also consulted from A, P and Chinese Virtual Herbarium (www.cvh.org.cn). Herbarium acronyms follow Thiers (2016). Flower colors of Berberis species were observed and photographed in the field. In order to achieve a comprehensive understanding of the range of ovule number of B. sanguinea, from May to 8 May 2014, in 3 townships of Baoxing, 20 ovaries or young fruits were randomly sampled from each of 11 mature shrubs in Qiaoqi, 5 shrubs in Longdong, and 6 shrubs in Yongfu, respectively. In total, 440 ovaries or young fruits were sampled from 22 mature shrubs of B. sanguinea, which all produced the typical purplish red or bicolored flowers in the flowering season. In the laboratory, all the ovaries or young fruits were longitudinally dissected to reveal their ovules, and all the floral parts were observed and photographed by a CCD on Nikon SMZ 1000 Stereomicroscope.

Pollen grains of B. sanguinea were taken from the specimen, X. H. Li, L. C. Zhang & W. H. Li 140501 (NAU) collected from Qiaoqi Township of Baoxing. Pollen grains of the two new taxa were sampled from their holotypes. Pollen grains were processed according to the acetylsol method of Erdtmann (1969), then, mounted on slides with glycerine jelly for observation under an Olympus Stereomicroscope. In the laboratory, all the ovaries or young fruits were longitudinally dissected to reveal their ovules, and all the floral parts were observed and photographed by a CCD on Nikon SMZ 1000 Stereomicroscope. Data presented in parentheses are shown in means ± SD. For scanning electron microscopy (SEM) observations, pollen grains were mounted directly on copper stubs with double-sided adhesive tape, sputter-coated with gold, and examined using a Hitachi S3000 SEM. Terminology of pollen morphology basically follows Erdtmann (1969), Nowické and Skvarla (1981), Punt et al. (2007) and Hesse et al. (2009).

Data analysis was performed on SPSS 13.0 for Windows, using the nonparametric test, Kruskal–Wallis H Test and Mann–Whitney U Test.

3. Results

3.1. Morphological features of pollen grains

Pollen grains of the three taxa are spheroidal with spiraperture or interconnected spirapertures, exine ornamentation punctate and subspilulate (Table 1, Fig. 2). The polar axis is 41.69–57.57 (47.40 ± 3.22) μm; the equatorial axis is 38.46–51.65 (44.88 ± 2.75) μm.

| Table 1 | Pollen grain features of Berberis sanguinea and its affinitive two new taxa. |
|---------|---------------------------------------------------------------|
| Characters | B. sanguinea var. sanguinea | B. sanguinea var. viridisepala | B. viridiflora |
| Shape | Spheroidal | Spheroidal | Spheroidal |
| Polar axis (μm) | 46.30 ± 2.62 | 48.14 ± 3.71 | 47.74 ± 3.09 |
| Equatorial axis (μm) | 44.03 ± 1.89 | 45.18 ± 3.65 | 45.44 ± 3.23 |
| P/E | 1.05 ± 0.04 | 1.07 ± 0.04 | 1.05 ± 0.04 |
| Aperture width (μm) | 1.94 ± 0.32 | 1.99 ± 0.39 | 2.23 ± 0.34 |
| Aperture type | Spiraperture, and interconnected spirapertures | Interconnected spirapertures | Interconnected spirapertures |
| Exine ornamentation | Punctate and subspilulate | Punctate and subspilulate | Punctate and subspilulate |

Values in the same row with different letters indicating significant difference at p < 0.05 level.
3.2. Taxonomic treatments

3.2.1. Berberis viridi X. H. Li, sp. nov. (Figs. 3 and 4) 绿花小檗 (lv hua xiao bo)

**Type:** China. Sichuan Province: Baoxing County, Longdong Township, Donglashan Valley, 30°25.55′N, 102°33.65′E. Alt. 2085 m. 2014-05-06, X. H. Li, L. C. Zhang & W. H. Li; C–D. B. sanguinea Franch. var. viridisepala (Figs. 3 and 4).

**Diagnosis:** B. viridi B. sanguinea var. viridisepala resembles two sympatric congeners, B. sanguinea and B. multiovula, in the morphology of leaves, berries, and branches, but differs obviously by the greenish flowers, the apex of petals being truncate, obtuse, or undulate (Figs. 4 and 7), and the wider interconnected spirapertures of pollen grains (Fig. 2).

**Description:** Evergreen shrubs to 1.2 m tall. Old stems dark gray; 2-year-old branches gray, sulcate, nearly glabrous. Spines 3–11, central spines 0.4–2.6 cm. Leaves coriaceous, linear-elliptic or linear-lanceolate, 1.9–3.8 × 0.4–0.6 cm; abaxial surface gray green, adaxial surface lustrous dark green, margins with 2–10 spinescent teeth on each side, apex acute, spine-tipped, base cuneate, usually blending into petiole; petiole indistinct; venation inconspicuously reticulate on both surfaces, midvein obviously raised below, depressed above. Flowers usually 2 or 3-fascicled, or sometimes solitary. Pedicels purplish red, 3.2–12 mm. Tepals 17–19, basally greenish, sometimes outer 2–5 small sepals reddish green or partially reddish. Outmost 3 sepals ovate or broadly ovate, 1.9–3.3 × 1.2–2.5 mm, 1–3-veined, apex acute. Middle 3 sepals closely adjacent to innermost 3 sepals ovate or ovate-elliptic, 3.9–5.6 × 2.8–4 mm, basally 3-veined, apex obtuse. Innermost 3 sepals obovate or obovate-elliptic, 5.3–6.8 × 3.6–5 mm, usually 3-veined, with a few lateral veins, central vein prominent, apex obtuse. The 6 nectariferous petals obovate, 3.6–4.7 × 2–3.5 mm, 3-veined, with a few lateral veins, apex truncate, obtuse, or undulate, base cuneate, nectaries ovate-elliptic. Stamens 6, 2–2.5 mm, connectives truncate. Pistil barrel-shaped, 2.6–3.4 mm, style almost absent, stigma peltate. Ovules 3–5. Berries purplish brown or purplish-black, ovoid-ellipsoid, 8.7–12.6 × 3.9–6.9 mm; persistent style inconspicuous; stigma disk-like. Seeds 1–5, brown or purplish brown, ovoid-ellipsoid, 4.8–5.1 × 2.1–2.7 mm.

In November 2013, during the first field survey of Berberis species in Donglashan Valley of Baoxing County, we found two mature shrubs with the typical gray, sulcate branches, and linear-elliptic or linear-lanceolate leaves of B. sanguinea, growing in a thicket about 3 m apart. One shrub brought forth not only black ellipsoidal berries, but also the typical purplish red flowers of B. sanguinea in early winter. However, we were deeply impressed by the purplish brown, broadly ellipsoidal berries of another shrub (Fig. 4C). During the second field investigation in Donglashan Valley on 6 May 2014, we were again strongly impressed by the fact that, the shrub, which produced purplish brown, broadly ellipsoidal berries last November, gave forth all greenish flowers. Subsequent observation in laboratory has shown that 36 nectariferous petals of 6 greenish flowers, which were sampled from the type shrub (Fig. 4B), were all...
truncate, obtuse or occasionally undulate at the apex. On the contrary, 426 nectariferous petals of 71 purplish red or bicolored flowers, which were sampled from 19 mature shrubs of *B. sanguinea* in Baoxing County, were all notched to emarginate at the apex. In addition, in Baoxing, some shrubs of *B. sanguinea* were observed still bringing forth purplish red flowers in October and November between 2013 and 2014, however, in the meantime, no greenish flower was found on any shrub resembling *B. sanguinea* in early winter. As a result, we consider it inappropriate to assign this distinctive shrub to *B. sanguinea*, but appropriate to treat it as a separate new species.

**Phenology**: Flowering from April to May, fruiting from June to December.

**Etymology**: The specific epithet of this new species refers to its flower color being greenish.

**Distribution and habitat**: *B. viridi*flora is known only from Donglashan Valley of Baoxing County, growing in thicket beside mountain stream (Figs. 1 and 3), co-occurring with *B. sanguinea*.

**Selected specimens examined**: China. Sichuan Province: Baoxing County, Longdong Township, Donglashan Valley, 30°25.55′N, 102°33.65′E. Alt. 2085 m. 2013–11–04. X. H. Li & L. C. Zhang 131115 (paratype: NAU!). Both the paratype and the holotype were collected from the same living shrub.

**Similar species**: *Berberis panlanensis* Ahrendt was established based on the holotype Wilson 2875. On 21 June 1908, Mr. Wilson collected the holotype in Pan Lan Shan of western Sichuan Province and recorded that its flowers were yellow and bronze (Ahrendt, 1939). While in cultivated plants of *B. panlanensis*, its flowers were reported as basically greenish yellow or pale greenish (Ahrendt, 1939, 1961). During a revision of *Berberis* section *Wall-ichianae*, Chamberlain and Hu were unable to find the holotype of *B. panlanensis*, which was considered as being preserved in K (Ahrendt, 1939); they concluded that the holotype was possibly collected from a cultivated shrub, and it was an obscure species (Chamberlain and Hu, 1985). Whereas, at present, the isotype of *B. panlanensis* is still preserved in A, the holotype is probably missing in K. Although *B. panlanensis* has already been treated as a synonym of *B. sanguinea* by Chamberlain and Hu (1985), according to the isotype and related descriptions (Ahrendt, 1939, 1961), some key morphological features, especially the flower color, whether yellow and bronze or greenish yellow and pale greenish, and the brownish yellow branches and twigs, can obviously distinguish *B. panlanensis* from *B. sanguinea*. As a result, it is reasonable to remain *B. panlanensis* as a separate species. *B. viridi*flora is similar to *B. panlanensis*, but differs by the apex of petals being truncate or obtuse, the gray sucule branches or twigs, and the shape of leaves.

3.2.2. *Berberis sanguinea* Franch. var. *viridisepala* X. H. Li, L. C. Zhang & W. H. Li, var. nov. (Figs. 3 and 5)  绿萼小檗 (lv e xiao bo)

**Type**: China. Sichuan Province: Baoxing County, Longdong Township, Donglashan Valley, 30°25.47′N, 102°33.58′E. Alt. 2086 m. 2014–05–06. X. H. Li, L. C. Zhang & W. H. Li 140513 (holotype: NAU!).

**Diagnosis**: *B. sanguinea* var. *viridisepala* resembles *B. sanguinea* Franch. var. *sanguinea* and *B. multiovula* in the morphology of branches, leaves, berries, and in the nectariferous petals retuse at apex, especially a minority of purplish red or bicolored flowers co-occurring on the branch (Fig. 5A), but this new variety differs obviously by the greenish or yellowish green flowers. *B. sanguinea* var. *viridisepala* is also similar to *B. viridi*flora, but differs by the absence of petals being truncate or obtuse at apex.

**Description**: Evergreen shrubs to 2.1 m tall. Old stems dark gray; 2-year-old branches gray, sucule, nearly glabrous. Spines 3-fid, sometimes 5-fid, central spines 0.6–2.3 cm. Leaves coriaceous, linear-elliptic or linear-lanceolate, 2.3–5.2 × 0.4–0.8 cm; abaxial surface gray green, adaxial surface lustrous dark green, margins with 4–15 spinescent teeth on each side, apex acute, spine-tipped, base cuneate, usually blending into petiole; petiole margins with 4–15 spinescent teeth. Tepals 16, basically pale green or yellowish, often 3-veined, apex obtuse. Innermost 3 sepals ovate or obovate-elliptical, 5.4–6.9 × 4.4–5.9 mm, usually 3-veined, with a few lateral veins, central vein prominent, apex obtuse. Nectariferous petals 6, rarely
5, obovate, 3.9–5.1 × 2.5–3.9 mm, 3-veined, with a few lateral veins, apex emarginate, base cuneate, nectaries linear-elliptic. Stamens 6, rarely 5, 2.6–3.1 mm, connectives truncate. Pistil barrel-shaped, 3–3.4 mm, style almost absent, stigma peltate. Ovules 3–7. Berries purple or purplish black, ovoid-ellipsoid or ellipsoid, 8.9–12.7 × 3.5–6.0 mm; persistent style inconspicuous; stigma disk-like. Seeds 1–5, brown or purplish brown, obovoid-ellipsoid, 4.3–5.3 × 2.1–2.4 mm.

**Phenology:** Flowering from April to May, fruiting from June to December.

**Etymology:** The specific epithet of this new variety refers to its sepals being greenish or yellowish green.

**Distribution and habitat:** *B. sanguinea* var. *viridisepala* is known from Baoxing and Kangding counties, central-west Sichuan Province, growing on the cliffs and in thickets along the mountain stream (Figs. 1 and 3), co-occurring with *B. sanguinea* var. *sanguinea* in Baoxing County, and with *Berberis verruculosa* Hemsl. et E. H. Wilson in Kangding County.

**Selected specimens examined** (all paratypes): China. Sichuan Province: Baoxing County, Longdong Township, Donglashan Valley, 30°25.47′N, 102°33.58′E. Alt. 2086 m. 2013-11-04. X. H. Li & L. C. Zhang 131117 (NAU!), both this paratype and the holotype were collected from the same living shrub; 30°25.38′N, 102°33.47′E, Alt. 2084 m. 2014-05-06. X. H. Li, L. C. Zhang & W. H. Li 140514, 140516 (NAU!); Kangding County, Paoma Mountain, 30°02.67′N, 101°58.12′E. Alt. 2789 m. 2014-05-11. X. H. Li, L. C. Zhang & W. H. Li 140554, 140555 (NAU!).

**3.2.3. Berberis sanguinea** Franch. var. *sanguinea* (Figs. 6 and 7)

**血红小檗**

**Type:** China. Sichuan Province: Mupin (Baoxing County), April 1869, David s.n. (holotype: P00716571, P, image!).

*B. multiovula* T. S. Ying in Acta Phytotax. Sin. 37(4): 309, 1999. Syn. nov. Type. China. Sichuan Province: Baoxing County, Puxi Valley. Alt. 2900 m. 1959-05-03. Sichuan Economic Plants Expedition 293 (holotype: PE!; isotype: KUN!).

Both the holotypes of *B. multiovula* and *B. sanguinea* var. *sanguinea* were collected from Baoxing County. According to the field record of the holotype, flowers of *B. multiovula* are purplish red outside and greenish inside, the key difference between the two sympatric congeners was considered to be the 5-ovuled ovary of *B. multiovula* (Ying, 1999), despite their similarity in characteristics of flowers, leaves, branches and twigs. Furthermore, records of ovule number were not found in the protologue or on the holotype of *B. sanguinea* var. *sanguinea* (Franchet, 1885), though 2- to 3-ovuled ovaries were reported later (Ahrendt, 1961; Ying, 2011).
Among the 440 ovaries or young fruits sampled from 22 mature shrubs of *B. sanguinea* var. *sanguinea*, the ovule number was found varying greatly from 2 to 9 (Fig. 6C–J), mean ± SD = 4.2 ± 1.1. Eleven variation patterns of the ovule number have been observed from the 22 shrubs, i.e. 2- to 4-ovuled, 3- to 4-9-ovuled, and 4- to 7–9-ovuled, and 7 shrubs all contain only 3- to 5-ovules. The ovule number is significantly different ($\chi^2 = 176.006$, df = 21, $P < 0.001$) among the 22 mature shrubs of *B. sanguinea* var. *sanguinea* sampled in 3 townships of Baoxing County, but it is not apparently different ($\chi^2 = 2.259$, df = 2, $P = 0.323$) among three populations from the three townships.

Although the locality of holotype of *B. multiovula* was recorded as Puxi Valley of Baoxing County, even local experienced or elderly residents are confused as to its exact locality, and the most similar site to Puxi Valley is now known as Puji Valley in Yongfu Township of Baoxing. Furthermore, the isotype of *B. multiovula* preserved in KUN was identified as *B. sanguinea* by professor Zhengyi Wu. Thus, it is appropriate to treat *B. multiovula* as a synonymy of *B. sanguinea* var. *sanguinea*.

**Supplementary description:** Evergreen shrubs to 3.5 m tall. Old stems dark gray; 2-year-old branches gray, sulcate, nearly glabrous. Spines usually 3-fid, central spines 0.5–3.6 cm. Leaves coriaceous, linear-elliptic or linear-lanceolate, 1.4–6.2 × 0.3–1 cm; abaxial surface grey green, adaxial surface lustrous dark green, margins with 3–15 spinescent teeth on each side, apex acute, spine-tipped, base cuneate, usually blending into petiole; petiole indistinct; venation inconspicuously reticulate on both surfaces, midvein obviously raised below, depressed above. Flowers 2–6-fascicled, or...
Fig. 6. Variation patterns of stamens and ovule number of *Berberis sanguinea* Franch. var. *sanguinea*. A–B. Two stamens with the apex of connectives being truncate (A) and apiculate (B); C–J. Longitudinally dissection of ovaries, showing 2-(C), 3-(D), 4-(E), 5-(F), 6-(G), 7-(H), 8-(I), and 9-ovuled (J) ovaries. Photos A–B by Wenhui Li, C–J by Licun Zhang. Scale bars: A–J = 1 mm.

Fig. 7. Morphological features of *Berberis sanguinea* Franch. var. *sanguinea* from Baoxing County. A–B. Purplish red or bicolored flowers from Qiaoqi Township; C. Bicolored flowers from Yongfu Township, the outer sepals purplish red, while the inner petals greenish yellow; D. Purplish red flowers and ripen purplish black berries from Longdong township, photographed in November 2013; E. Outermost sepal; F. Middle sepal; G. Innermost sepal; H–J. Three purplish or yellowish nectariferous petals, with the apex being notched or emarginate. Photos A–D by Xinhua Li, E–J by Licun Zhang. Scale bars: A–D = 1 cm; E–J = 1 mm.
solitary. Pedicels purplish red or purple, 3–18.5 mm. Tepals 13–22, mostly 17 or 18, sepals purplish red, nectariferous petals purplish red, reddish or greenish yellow. Outermost 3 sepals ovate, 1.6–4 × 1–3.1 mm, often 3-veined, apex obtuse, seldom acute. Middle 3 sepals closely adjacent to the innermost 3 sepals ovate or ovate-elliptic, 2.7–5.8 × 2.1–4.9 mm, 3–5-veined, apex obtuse. Innermost 3 sepals broadly ovate or broadly obovate-orbicular, 4–6.8 × 2.2–5.9 mm, usually 3-veined, with a few lateral veins, central vein prominent, apex obtuse or rounded. Nectariferous petals mostly 6, obovate, 2.8–5.8 × 1.7–4.5 mm, 3-veined, with a few lateral veins, apex notch or emarginate, base cuneate, nectariferous ovate-elliptic. Stamens often 6, 2.1–3.2 mm, connectives usually truncate, seldom apiculate. Pistil barrel-shaped, 2.5–3.4 mm, style almost absent, stigma peltate. Ovules 2–9. Berries purplish black, ellipsoid or ovoid-ellipsoid, 8–12.7 × 3.5–6.9 mm; persistent style inconspicuous; stigma disk-like. Seeds 1–7, obovoid-ellipsoid, brown or purplish brown, 4.3–5.3 × 2.1–2.4 mm.

**Phenology:** Flowering from April to May, fruiting from June to December.

**Distribution and habitat:** Distributed in Baoxing, Lushan, Tianquan, Luding, Kangding, Danba, Jinchuan, Xiaojin, Dujiangyan and Wenchuan counties (Fig. 1), central-west Sichuan Province, growing in thickets or forests on mountain slopes, or along mountain streams.

**Selected Specimens Examined (vouchers):** China. Sichuan Province: Baoxing County, Qiaqiao Township, Jiuluo Village, 30°41.3′N, 102°43.15′E. Alt. 2382 m. 2014-05-05. X. H. Li, L. C. Zhang & W. H. Li. 140501 (4-9-ovuled), 140503 (3-8-ovuled), 140504 (3-9-ovuled); Baoxing County, Longdong Township, Dongglashan Valley, 30°25.52′N, 102°33.68′E. Alt. 2085 m. 2014-05-06. X. H. Li, L. C. Zhang & W. H. Li. 140509 (3-5-ovuled), 140510 (3-4-ovuled), 140512 (3-5-ovuled); Baoxing County, Yongfu Township, Puji Valley, 30°34.77′N, 102°30.65′E. Alt. 2121 m. 2014-05-07. X. H. Li, L. C. Zhang & W. H. Li. 140518 (4-7-ovuled), 140521 (3-6-ovuled) (all specimens: NAU).

### 3.2.4. Species diversity of *Berberis* from Baoxing County

On the basis of field surveys and study of herbarium specimens, a total of 16 species and varieties of *Berberis* have been recorded from Baoxing County, and a key is provided here. As shown by the key below, five species and one variety are deciduous shrubs, eight species and two varieties evergreen shrubs. Their branches vary from gray, sulcate, nearly glabrous, e.g. *B. sanguinea* var. *sanguinea*, to brownish yellow, terete or subterete, densely verrucose, e.g. *B. verruculosa* and *B. baoxingensis*. The verrucose feature of branch surface in fact consists of dense, strongly raised columnar lenticels, which is revealed by SEM observation (Li et al., 2015a). Inflorescences of the 16 taxa are diverse, 12 species and varieties bear solitary or fascicled flowers, two species give forth racemes or umbellate racemes, and the other two species produce congested or spreading panicles. Based on field observations, partially in combination with analysis of literature (Ahrendt, 1961; Ying, 2011), among the 16 taxa, the ripe berries of five species and one variety are red or pinkish red, oblong, oblong-ovoid, ovoid, ovoid-globose or subglobose; three species and two varieties have berries that are purplish brown, purplish or purplish black in color, ellipsoid, ovoid-ellipsoid or ovoid in shape, pruinose or glabrous; however, both color and shape of the ripe fruits still remain unclear for the other five species.

**Key to Berberis species from Baoxing County**

1. Flowers arranged in an umbellate raceme, raceme, or panicle, deciduous shrubs .................................................. 2

1. Flowers solitary or fascicled, shrubs usually evergreen, or deciduous ........................................................................... 5

2. Inflorescence a raceme, or an umbellate raceme .................................................................................................................. 3

2. Inflorescence a panicle ............................................................................................................................................................. 4

3. Raceme 18–60-flowered, 7–18 cm; berries red, oblong .......................................................... 6. *B. feddeana*

3. Mostly an umbellate raceme, 4–12-flowered, 3–8 cm; berries red, oblong .................................................. 12. *B. silva-taroucana*

4. Panicle congested, 10–30-flowered, 1.5–3 cm; berries red, subglobose or ovoid-globose .................................................. 1. *B. aggregata*

4. Panicle 15–80-flowered, 4–10 cm; berries pink, ovoid ................................................................................................. 9. *B. prattii*

5. Deciduous shrubs, leaf margin usually entire ........................................................................................................................ 6

5. Evergreen shrubs, leaf margin spinose-serrate ..................................................................................................................... 7

6. Flowers 3–8-fascicled, pedicels less than 1 cm; berries pinkish red, subglobose ................................................................. 16. *B. wilsoniae* var. *wilsoniae*

6. Flowers usually solitary, pedicels 1–3 cm; berries red, ovoid or oblong-ovoid ............................................................ 8. *B. multiensis*

7. Leaves linear-elliptic or linear-lanceolate; flowers purplish red, greenish, yellowish green, or sepals purplish red, petals greenish yellow ................................................................................. 8

7. Leaves elliptic, ovate-elliptic, oblong-elliptic, elliptic-lanceolate or lanceolate; flowers yellow, or outer sepals purplish red, inner sepals and petals yellow ........................................................................ 10

8. Flowers basally greenish, apex of petals truncate, obtuse or undulate; berries purplish brown or purplish-black, ovoid-ellipsoid ........................................................................................................ 15. *B. viridiflora*

8. Apex of petals emarginate or notched ................................................................................................................................. 9

9. Flowers purplish red, or sepals purplish red, petals greenish yellow, apex of petals emarginate or notched; berries purplish black, ellipsoid or ovoid-ellipsoid ........................................ 10. *B. sanguinea* var. *sanguinea*

9. Flowers basally yellowish green, apex of petals emarginate; berries purple or purplish-black, ovoid or ovoid-ellipsoid ........................................... 11. *B. sanguinea* var. *viridinepala*

10. Flowers usually solitary, pedicels longer than 2.5 cm; leaves elliptic, margin with 1–4 appressed spinules per side ................................................................................................................................. 2. *B. asmyana*

10. Flowers solitary, or 2–18-fascicled, pedicels shorter than 2.5 cm ................................................................................................. 11

11. Branches brownish yellow, obviously verruculose; leaves ovate-elliptic or elliptic; flowers solitary, or 2–4-fascicled .......................................................... 12

11. Branches brownish yellow or gray; leaves lanceolate, elliptic-lanceolate, oblong-elliptic, or elliptic; flowers 2–17-fascicled .................................................................................................................. 13

12. Branches terete; leaves ovate-elliptic, pruinose below; flowers yellow, fragrant; berries purple or purplish black, pruinose, ovoid or ovoid-ellipsoid .......................................................... 14. *B. verruculosa*

12. Branches subterete; leaves elliptic, gray green below; outer 3–6 sepals purplish red or pink; berries purple or purplish black, ovoid or ovoid-ellipsoid .................................................................................. 5. *B. bergmanniae*
13. Leaves lanceolate or elliptic-lanceolate .........................

14. Branches gray, angled to sulcate; leaf margin with 5–10 appressed spines per side; pedicels 0.5–1 cm

14. Leaf margin with dense spreading spinescent teeth; pedicels 0.7–2 cm ........................................ 15

15. Leaf margin with 6–20 spinescent teeth per side; flowers 2–8-fascicled, pedicels 1–2 cm

7. B. gagnepaini

15. Leaf margin slightly undulate, with 10–30 spinescent teeth per side; flowers 4–12- fascicled, pedicels 0.7–2.5 cm

13. B. veitchii

4. Discussion

The two new taxa with greenish flowers, B. viridi*flora* and B. sanguinea var. *viridisepala*, accompanied by B. sanguinea var. *sanguinea* and B. × *baoxingensis* with distinctive purplish red or bicolor flowers, have greatly enriched the floral diversity of *Berberis* in China, and their geographical distribution is basically confined to Baoxing County and its adjacent Sichuan Giant Panda Sanctuaries (Fig. 1). Based on the above key to *Berberis*, the 16 species and varieties recorded in Baoxing County contain a great majority of the phenotypic variations of Chinese *Berberis* (Ahrendt, 1961; Ying, 2011), including both evergreen and deciduous habit, most morphological variation patterns of stems, branches and leaves, all types of inflorescences, all color types of flowers, and nearly all types of the shape and color of fruits. Consequently, species diversity of Chinese *Berberis* is well represented in Baoxing County. This county and the adjacent Sichuan Giant Panda Sanctuaries possibly constitute an active diversification center of *Berberis* in eastern Hengduan Mountains of China. A lot of studies have indicated that rapid species diversification has occurred in Hengduan Mountains during the extensive uplift of the Qinghai–Tibetan Plateau (Li and Li, 1993; Wen et al., 2014). favored by the extremely complex topography and a diversity of habitats, Hengduan Mountains have become an important biodiversity hotspot in the world, holding very high species richness and endemism of Chinese seed plants (Huang et al., 2016; Zhang and Ma, 2008; Zhang et al., 2009).

Considering the present conservation status of the two new taxa, at present, B. viridi*flora* is known only from the type locality based on a 2-years field survey, and only one mature shrub has been found within an area of ca. 0.16 km² along the mountain stream in Donglashan Valley of Baoxing County. Consequently, we assign *B. viridi*flora* a preliminary IUCN Red List Category of Critically Endangered (CR: B1, B2ab, D), according to the guidelines prepared by IUCN (2016). Similarly, B. sanguinea var. *viridisepala* is assigned a preliminary endangered status (En: B1, B2ab, D). In addition, we also assign a preliminary endangered status (En: B1, B2ab, D) for B. × *baoxingensis*, which has recently been reported as a new species from Qiaoqi Township of Baoxing County (Li et al., 2015a).

Natural disasters, especially earthquakes and associated landslides and debris flows, have caused profound damage to the natural vegetation of Sichuan Giant Panda Sanctuaries including Baoxing County (Ouyang et al., 2008; Yang et al., 2011; Zeng et al., 2014; Zhang et al., 2014). Baoxing is very rich in ecotourism resources (Zhou and Zhu, 2004), as tourism or ecotourism has been promoted within the Sichuan Giant Panda Sanctuaries (He et al., 2008; Yang et al., 2011). However, during the construction of tourism infrastructures, such as building highways, paths, and related tourist service facilities in the mountainous scenic areas, natural forests have been inevitably disturbed. This is particularly true for many living shrubs of *Berberis* species growing along the tour routes or beside trails in the mountains that are easily susceptible to cutting or even uprooting. Both natural disasters and human disturbances during tourism development will potentially bring considerable threats to the perpetual survival of some species of *Berberis* in the wild, especially those rare species with extremely low species abundance, e.g. B. viridi*flora*, B. sanguinea var. *viridisepala* and B. × *baoxingensis*. As a result, in situ conservation of the *Berberis* species with greenish or bicolor flowers is recommended as a first priority, while ex situ conservation of these species in botanical gardens and arboretsums is also urgently required.

Acknowledgments

We are grateful to the curators of BM, E, K, KUN and PE for permission to visit their herbaria, and to the curators of A and P for access to images of *Berberis* specimens in their collections. We thank Mr. Ziyi He for his technical assistance in SEM observation. Our thanks are also expressed to the editors for helpful comments and suggestions. This work was supported by the National Natural Science Foundation of China (Grant No. 31107014), and the S & T Basic Work, Ministry of Science and Technology of the People's Republic of China (Grant No. 2013FY112100).

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