Perspective

The new species and the third Chinese member of Colubrina (C. zhaoguangii, Rhamnaceae)

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**ABSTRACT**

A novel species of Rhamnaceae, \textit{Colubrina zhaoguangii}, is discovered in Sichuan, China, during the biodiversity investigations of the Second Tibetan Plateau Scientific Expedition and Research. Detailed descriptions and illustrations of the new species are presented herein. To date, the new species is only found in dry-warm river valleys of the Jinsha River basin in the Hengduan Mountains region (HDM). Compared with the other two known Chinese \textit{Colubrina} species, \textit{C. zhaoguangii} features by the habit of twisted shrub and tiny leaves with emarginate apex. In morphology, the new species highly resembles \textit{C. alluaudii} endemic in Madagascar and \textit{C. viridis} in northwestern Mexico, whereas it is distinguished from these two relatives by its minutely white scales on the leaf blades. The discovery of \textit{C. zhaoguangii} reminds us again that the bottom region is also important for biodiversity conservation in HDM and should be a flora survey priority.

**Introduction**

\textit{Colubrina} Rich. ex Brongn. is a Rhamnaceae genus of small trees or scendant shrubs. This genus was proposed in a manuscript by Richard and taken up and described by Brongniart (1826). According to Johnston (1971), \textit{Colubrina} consisted of 31 tropical and subtropical species, while the accepted members have increased to 38 based on the records on the web of Plants of the World Online (http://powo.science.kew.org/). Except for \textit{C. asiatica} (L.) Brongn., which depends on ocean currents to disperse propagules and shows a pan-tropical distribution (McCormick 2007), no \textit{Colubrina} members with cross-continental distribution have been reported. Most \textit{Colubrina} species occur in tropical America, but there are also six endemics in Southern Africa and Madagascar, three endemics in tropical Asia, and single endemic each in Oceania (Hawaii) and Australia (Christmas Island). In China, two \textit{Colubrina} species are recorded, i.e., \textit{C. asiatica} and \textit{C. javanica} Miq.; the former occurs along the beaches in Guangdong, Guangxi, Hainan, and Taiwan, and the latter grows along the riverbanks in southern Yunnan (Chen and Schirarend 2007).

The Hengduan Mountains region (HDM) in southwest China is one of the earth’s 36 biodiversity hotspots (Brooks et al. 2006; Myers et al. 2000). It is also a conservation priority given the considerable diversity of both species and ecological regions (Xu et al. 2019; Zhang, Silk, and Ma 2017). The river valley ecosystem in the mountain bottom areas is an important part of the HDM, it harbors a heat- and drought-tolerant flora with high plant diversity (Jin 1998, 1999; Jin, Yang, and Tao 1995; Sun et al. 2017; Zhang et al. 2021; Zhu 2014). However, only a few large-scale flora surveys were conducted in valley regions of HDM before 2000, due to the precipitous topography, harsh environment, and poor transportation therein. During the last 20 years, great progresses were achieved in the studies on plant diversity in China, as well as in valley regions of HDM (Du et al. 2020; Zhu 2014). According to Zhu’s (2014), the river valleys in HDM harbor more than 2400 species of spermatophyte. Among them, 30 species belong to six genera of Rhamnaceae, i.e., \textit{Berchemia} Neck., \textit{Paliurus} Tourn ex Mill., \textit{Rhamnella} Miq., \textit{Rhamnus} L., \textit{Sageretia} Brongn., and \textit{Ziziphus} Mill., without \textit{Colubrina} members reported.

During the HDM biodiversity investigations (the part of the Second Tibetan Plateau Scientific Expedition and Research Program) conducted from July to October 2021, we discovered two novel shrub populations in the valley of Dinggu River (a tributary of Jinsha River) in southwestern Sichuan. The tiny 5-merous flowers with clawed petals and the 3-loculed capsules basally surrounded by remnants of calyx tube identified them as the member of the genus \textit{Colubrina} (Rhamnaceae). This
identification was then proved correct by phylogenetic analyses based on four markers (ITS, trnL-F, matK, and rbcl). Moreover, the novel populations are morphologically different from the two known Colubrina species in China as well as all other members of the genus, thus probably representing a new species. After examining the morphological divergences between the novel Colubrina species and its closest relatives occurring in Madagascar and Mexico, respectively, we describe it as a new species herein.

Materials and methods

Phylogenetic analyses
To further confirm that the new species belongs to the genus Colubrina, we reconstructed the phylogenetic trees of the ziziphoïd lineage. Two samples of the putative new species were sequenced in this study. Additional sequence data for 51 species (ten of them belong to Colubrina) representing 37 genera of the ziziphoïds were retrieved from GenBank. We then amplified the internal transcribed spacer region (ITS), the trnL-trnF gene and spacer region, the maturase K gene (matK), and the ribulose-1,5-bisphosphate carboxylase/oxygenase large subunit gene (rbcl), for ITS and trnL-trnF following the protocols by Yang et al. (2017) and for matK and rbcl following Onstein et al. (2015). GenBank accession numbers of sequences were displayed in Table S1.

Phylogenetic trees were reconstructed based on Bayesian inference (BI) and maximum likelihood (ML) approaches. We employed jModeltest 2.1.7 (Darriba et al. 2012) to determine a best-fitting nucleotide substitution model (GTR + I + G) for BI analysis, with the Bayesian information criterion (BIC) performed. BI analyses were then implemented using MrBayes (Ronquist et al. 2012) with the following settings: ngen = 5,000,000, samplefreq = 1000, printfreq = 1000, and sumt burnin = 1000. ML analyses were conducted using the CIPRES (http://www.phylo.org/; Miller, Pfeiffer, and Schwartz 2010) Science Gateway web server (RAxMLHPC2 on XSEDE) with 1,000 bootstrap replicates.

Morphological studies
Protologues of all published names of Colubrina were reviewed and collated. Character examinations were based on specimens and field individuals for the putative novel species. Digital specimen images of the closest relatives, including C. alluaudii (H. Perrier) Capuron from Madagascar, and C. viridis (M.E.Jones) M.C.Johnst. from northwestern Mexico, were carefully examined. Involved herbarium abbreviations follow Thiers (2020).

Results
The combined dataset comprises 53 accessions and 2962 base pairs. Because there are no significant conflicts between the topologies of the ML tree and that of the BI tree, only the latter were displayed, with both posterior probabilities (BI-PP) and maximum likelihood bootstrap percentage (ML-BP) indicated (see in Figure 1).

All the sampled Colubrina members including the putative new species (finally named as C. zhaoguangii) have formed a monophyletic clade (BI-PP = 1.00/ML-BP = 100). Two individuals of C. zhaoguangii have formed an independent clade with strong support (1.00/100). Notably, C. zhaoguangii is close to the relatives from the American continent (C. arborescens (Mill.) Sarg., C. elliptica (Sw.) Brizicky & W. L. Stern, C. glandulosa Perkins, C. reclinata (L’Hér.) Bronn., and C. triflora Bronn.) and Hawaii (C. oppositifolia Bronn. ex H. Mann), rather than those also occurring in China (C. asiatica and C. javanica).

Compared to the other two climbing relatives with serrate and large leaves (> 40 mm long) in China, Colubrina zhaoguangii, the new shrub species, is distinguishable as it has entire and tiny leaves (< 20 mm long). Factually, C. zhaoguangii is similar to C. alluaudii, but they show distinct discrepancies in terms of leaf blade size [5–15 (–20) x 4–10 mm in C. zhaoguangii vs. (7–) 15–50 x 6–40 mm in C. alluaudii], color of indumentum (white vs. reddish-brown), and position of gland (at the apex of petiole vs. apex of blade). The new species also highly resembles C. viridis, but differs from the latter in having densely pubescent buds, branchlets, stipules, petioles, pedicels, and calyces (vs. glabrous to sparsely pubescent in C. viridis). Moreover, the key character peculiar to Colubrina zhaoguangii – the densely-minutely white scales on leaf blades (Figure 2e and Figure 3d) – distinguishes it from both C. alluaudii and C. viridis (seen in Table 1).

Discussion
Coinciding with the indication from morphological characters, phylogenetic analyses also suggest an identification of Colubrina to the new species, although the relationships between C. zhaoguangii and the Hawaiian and tropical American relations have not been well resolved. Due to the lack of DNA materials, we cannot amplify more effective markers to achieve a better resolved phylogeny of Colubrina. Nonetheless, C. zhaoguangii is clearly distinguished from the closest phylogenetic relatives, as the leaves of the former are papery, entire, and small (< 20 mm long) while that of the latter are leathery, serrated, and much larger (> 60 mm long) (Nesom 2016).
It is noteworthy that high similarity in shape and size of leaf blade shared by *C. viridis* and *C. zhaoguangii* should probably be the results of convergent evolution, as they are all harbored in arid zones. Dry-warm river valleys in HDM (DWRV-HDM) and tropical deserts in northwestern Mexico (TD-WM), where *C. viridis* occurs in, factually have similar appearance of vegetation, which is dominated by dwarf, twisted, and spiny bushes with small leaves (Dallman 1998; Jin 2002; Liu et al. 2016). Morphological convergence following the same pattern can also be found in Sageretia (another genus of Rhamnaceae). S. yilinii G.S.Fan and S.K.Chen (found in DWRV-HDM) extremely resemble S. wrightii S.Watson (in TD-WM), although they were clustered in different lineages (Yang et al. 2019). A combination of characters – branches terminating in woody thorns and small obovate leaf blades with emarginate apex – has also been well developed in several other shrub species in DWRV-HDM, such as *Flueggea monticola* G. L.Webster (Phyllanthaceae) and *S. horrida* S.K.Hoffm (Rhamnaceae). Thus, it is not easy to recognize *C. zhaoguangii* when both flowers and fruits are absent.

Based on the present data, we decline the long-distance dispersal hypothesis to explicate the disjunctions between *C. zhaoguangii* and the resemblances. On the one hand, the capsules of *Colubrina* are not suitable for transoceanic dispersal by winds or animals (Higgins, Nathan, and Cain 2003; Gillespie et al. 2012). On the other hand, the remaining route, dispersal by ocean currents, is particularly relevant for littoral plants (Nathan et al. 2008; Liu et al. 2021), while the new species is found to be at a distance of at least 1,000 km from the closest coast.

**Figure 1.** The BI tree for the combined dataset (ITS + trnL-trnF + matK + rbcL). Support values ≥ 0.50 PP or 50 BP are shown above branches follow the order BI-PP/ML-BP. The dash (-) indicates a support value < 50 or PP < 0.50. The new species is shown in bold.
**Taxonomic treatment**

*Colubrina zhaoguangii* J.Hu & Yi Yang, sp. nov. (Figures 2–4)

**Chinese name:** hàn gǔ shé téng (旱谷蛇藤), reflecting that the new species grows in arid valleys.

**Type material.** CHINA. Sichuan: Garze Tibetan autonomous prefecture, Derong County, Guxue Town, Guxue Village (N 28.401667°, E 99.251800°), elev. 2172 m, 3 August 2021, J.Hu et al. hujun20210803B01 (holotype CDBI! isotypes IBSC! JXAU! LBG! NAS! PE!).

**Diagnosis.** The new species resembles *C. alluaudii* and *C. viridis*, but it can be easily recognized by the minutely white scales on the leaf blades. Compared to *C. alluaudii*, *C. zhaoguangii* also has smaller leaves [5–15 (–20) × 4–10 mm in *C. zhaoguangii* vs. (7–) 15–50 × 6–40 in *C. alluaudii*], white indumentum (vs. reddish-brown), and gland at the apex of petiole (vs. at the apex of blade) and to *C. viridis*, the new species also has densely pubescent buds, branchlets, stipules, petioles, pedicels, and calyces (vs. glabrous to sparsely pubescent in *C. viridis*).

**Description.** Shrubs up to 2 m tall. Buds, branchlets, stipules, petioles, pedicels, and calyces densely white pubescent. Branches alternate to subopposite, usually terminating in woody thorns; annual branches reddish purple, densely white pubescent, old branches gray to brown, glabrous. Leaves remotely alternate or nearly all of them fascicled at short shoots. Stipules subulate to linear, 1–3 mm. Petioles 1–10 mm. Leaf blades papyraceous, obovate or less commonly elliptic, 5–15 (–20) × 4–10 mm, adaxial surface densely minutely scaly, abaxial surface sparsely scaly and pubescent, lateral veins 3–4 pairs, usually ambiguous adaxially, prominent abaxially, base rounded to cuneate, margin entire, apex rounded to bluntly acute, usually emarginate, and...
Figure 3. *Colubrina zhaoguangii* J.Hu & Yi Yang drawn by C.Y. Li based on hujun20210803B01 (CDBI). a branch b leaf blade (adaxial surface) c leaf blade (abaxial surface) d glands at the apex of leaf blade e–f flower g fruit h seed.

Table 1. Comparison of habitat, morphological characters, and native range among *Colubrina alluaudii, C. viridis,* and *C. zhaoguangii* based on field observation, herbarium collections, and digital specimen images obtained from GBIF (https://www.gbif.org/), and descriptions of Johnston (1971).

| C. alluaudii | C. viridis | C. zhaoguangii |
|--------------|------------|---------------|
| Habitat      | Dry deciduous forest | Tropical desert | Dry-warm river valley |
| Buds, branchlets, petioles, pedicels, and calyces | Densely reddish-brown pubescent | Glabrous to sparsely pubescent | Densely white pubescent |
| Leaf blade size | (7–) 15–50 × 6–40 mm | 6–20 (–42) × 3–20 mm | 5–15 (–20) × 4–10 mm |
| Upper surface of leaf blades | Glabrous | Glabrous | Densely minutely scaly |
| Lateral veins | 3–6 pairs | 2–3 pairs | 3–4 pairs |
| Glands on leaves | 1–3 at the apex of petiole (near juncture of blade) | Absent or 1 on each side of blade margin (one-fourth to three-fifths the length from the base of blade) | 3 (–4) at the apex of blade |
| Native range | Madagascar | W Mexico | SW China |
borne with 3 (–4) glands. Flowers bisexual, 5-merous, solitary in the axils of the leaves. Pedicels 5–12 mm, in fruit elongating up to 15 mm. Calyx 4–5 mm in diam. (in bloom), tube hemispherical, sepals triangular-ovate, apex acute. Petals clawed, ca. 1.5 mm. Stamens as long as petals. Ovary immersed in stout disk, style 3-parted. Capsule 6–8 mm in diam., 3-loculed, basally up to ca. 1/4 surrounded by remnants of calyx tube; locules 1-seeded, loculicidally dehiscent at maturity. Seeds 4–5 mm long, smooth, shiny, broadly obovoid, reddish brown to dark brown, subtended at base by freshy arils.

**Phenology.** It starts to flower from July to August, its fruits are ripe in October.

**Etymology.** This species is named in honor of Prof. Zhao-guang Liu (1934–2001), a prominent vegetation ecologist from the Chengdu Institute of Biology, Chinese Academy of Sciences, for his significant work on vegetation protection of China, particularly in Hengduan Mountains area.

**Distribution and Habitat.** The species is native to southwestern Sichuan (Figure 5). It grows on arid slopes in valleys of the tributary of Jinsha River.
Additional specimens of *C. zhaoguangii* examined. CHINA. Sichuan: Garze Tibetan autonomous prefecture, Derong County, 50 km from Guxue Village (N 28.440104°, E 99.351541°), ca. 2200 m, 3 August 2021, J.Hu et al. CDhujun20210803P02S03 (CDBI); at the same locality, 30 September 2021, Y.Luo et al. DRluoyao20210930B01 (CDBI, KUN).

Specimens of *C. alluaudii* examined. MADAGASCAR. Antsiranana: Diana Region, 385 m, 22 March 2007, F.Ratovoson 1285 (MO). Toliara: 55 km NE from Morondava, 35 m, 18–19 March 1992, R.D.Noyes et al. 1027 (BR, MO); PK 894, N7, near Andranavory, 400 m, D.J.Mabberley 977 (P); Fort Dauphin Region, 120–140 m, 27 January 1990, G. McPherson & M.Pigeon 14,917 (P, MO); Fort Dauphin, Ranopiso, 200 m, 11 January 1995, S.Eboroke 955 (MO). Location unknown, Sept 1900, C.Alluaud 4 (syntype P00573429!).

Specimens of *C. viridis* examined. MEXICO. Baja California: Cacachilla Mountains, 2 October 1930, M.E. Jones 27,503 (isotype GH00048527!). Baja California Sur: ca. 3 km (air) SE of Todos Santos, 100 m, 18 December 1994, T.F.Daniel 6967 (SBBG); Sierra San Francisco, Canon Solidad, 700–800 m, 1 September 1995, W.Hodgson 9526 (DES). Durango: 5.1 miles S of El Refugio, ca. 1200 m (4000 ft), 21 July 1977, E.Lehto et al. L-21674 (ASU). Sonora: 4 miles east of Navajoa, 24 September 1955, B.
Templeton 7418 (SBBG); Guaymas, elevation unknown, 21 October 1939, H.S.Gentry 4674 (DES); Isla Tiburón, 3 kilometers west Punta Tormenta, 9 January 1977, N.Scott P11 (UNM); Rio Mayo Region, Freo. Sarabia, 175 m, 14 August 1994, S.L.Friedman 222–94 (ASU).

IUCN Red List Category

Colubrina zhaoguangii is currently only found in the dry-warm valleys in Derong, southwestern Sichuan, China. Although the dry-warm valleys are ecologically delicate, it is too remote and desolate to settle or graze livestock. Thus, the population has not been disturbed by human activity and currently grows well. According to our field investigations, the two known populations are 50 km apart, each comprises more than 30 plants, with seedlings, saplings, and fruiting individuals all found. Factually, more populations will probably be sought out, given that the large area of Jinsha River’s basin is outside the coverage of any expeditions. As a result, we recommend that C. zhaoguangii is categorized as Vulnerable (VU) based on criteria C1 and D in the IUCN Red List categories (IUCN 2019).

Key to the species of Colubrina in China

1 Shrubs; leaves blades less than 2 cm long, margin entire; flowers solitary .......................... .......................... C. zhaoguangii + Climbers; leaves blades larger, more than 4 cm long, margin serrulate; flowers in thyrses or cymes ........ .......................... .......................... C. asiatica

2 Young branchlets, petioles, inflorescences, and leaves glabrous; fruiting pedicle 4–6 mm ........ .......................... .......................... C. asiatica + Young branchlets, petioles, inflorescences, and leaves abaxially at least on veins pubescent or densely pubescent; fruiting pedicle 8–12 mm ........ .......................... C. javanica

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