New combinations in *Sarocalamus* for Chinese alpine bamboos (Poaceae: Bambusoideae)

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Sarocalamus was described for 3 high altitude bamboos from the Himalayas and SW China. They have strong morphological affinity to *Arundinaria*, which is now widely considered to be restricted to N America. Since the description of the genus additional potential members have come to light, and in molecular analyses they have been resolved in a clade with species already included in the genus. *Sarocalamus* has a Himalayan type but all other putative members of the genus are geographically disjunct from the Himalayan species. Within China they have been placed in *Arundinaria*, *Sinarundinaria*, *Bashania* and *Gelidocalamus*. Branching characters in a range of temperate bamboo genera were investigated, and strong similarities between the Himalayan type species and a species from N Yunnan were evident. Species from the Himalayas and China appear congeneric on morphological and phylogenetic grounds, and three further species are transferred into *Sarocalamus*.

Keywords: bamboo, *Bashania*, Bhutan, branching, China, *Gelidocalamus*, India, morphology, *Sarocalamus*

Introduction

While nearly all Asian species once considered to belong in *Arundinaria* had already been transferred into suitable genera on morphological grounds, a very small group of species from the Himalayas and SW China, with the strongest morphological affinity to the North American type species of *Arundinaria*, were felt to lack any appropriate genus (Stapleton et al. 2004). The name *Omeiocalamus* Keng f., had been mooted earlier in China for one such species, *Arundinaria fangiana* A. Camus, (Keng 1982), but it was soon disavowed by the author and placed in synonymy of *Gelidocalamus* T.H. Wen instead (Keng 1983), and the genus was never described.

Stapleton et al. (2004) had noted that while temperate Asian bamboos similar to the North American type species of *Arundinaria* Michx., *A. gigantea* (Walter) Muhl., had often been included in *Arundinaria* (Clayton & Renvoize 1986, Chao & Renvoize 1989, Stapleton 1994, Li 1997), the first molecular evidence (Zhang 1996, Ní Chonghaile 2002) was not showing any particularly close phylogenetic relationship between the N American species and those Asian species with the closest morphology, most of which were placed in *Bashania* Keng f. & T.P. Yi within China. Placement of a small group of

such species in *Bashania* or *Gelidocalamus* was excluded (Stapleton et al. 2004) on the basis of several clear morphological distinctions, their distinct ecological habitats, and also the a lack of support in molecular results for any close relationship.

Consequently the genus *Sarocalamus* Stapleton was described, with a well-known type species from the NE Himalayas, *S. racemosus* (Munro) Stapleton, and 2 similar species from Sichuan and NE Yunnan, *S. faberi* (Rendle) Stapleton (including *Arundinaria fangiana*) and *S. spanostachyus* (T.P. Yi) Stapleton, both of which were usually placed in *Bashania* in China (Keng & Wang 1996, Yi 1997), or kept in *Arundinaria* (Li 1997). *S. faberi* (including *A. fangiana)* had been comprehensively collected and was well known; *S. spanostachyus* much less so, and was included in a somewhat speculative manner.

For the Flora of China account (Li et al. 2006), because the molecular data was distinctly ambiguous at that time, the genera *Bashania* and *Sarocalamus* were not recognized and were given new status as *Arundinaria* subgenus *Bashania* (Keng f. & T.P. Yi) D.Z. Li and *Arundinaria* subgen. *Sarocalamus* (Stapleton) D.Z. Li.

Since publication of *Sarocalamus*, further molecular analyses have confirmed the placement of North American bamboos in a separate clade (Triplett & Clark 2010, Zeng et al. 2010, Zhang et al. 2012), and *Arundinaria* has become widely recognized in this narrow sense (Ohrnberger 1999, BPG 2012, Kellogg 2015, Vorontsova et al. 2016). Several species placed in *Sarocalamus* or described in *Bashania* have been included in later molecular analyses. Zeng et al. (2010) analysed 8 chloroplast gene regions from a large number of bamboos, including 7 species placed in *Bashania*. They could not show any association between the 7 species except for the resolution of *Bashania abietina* T.P. Yi & Lin Yang and *B. fangiana* in a well-supported clade (0.99PP), distinct from the other 5 species of *Bashania*, which included the type species, *B. qingchengshanensis* Keng f. & T.P. Yi. Zhang et al. (2012), using GBSSI gene sequences on a similar range of bamboos, recovered 5 *Bashania* species together in one of the most strongly supported clades within the entire Arundinarieae: *B. abietina*, *B. fangiana* (A. Camus) Keng f. & T.H. Wen, *B. qiaojiaensis* T.P. Yi & J.Y. Shi, *B. spanostachya* T.P. Yi, and *B. yongdeensis* T.P. Yi & J.Y. Shi. They referred to this as the 'Alpine *Bashania* clade'. *B. qingchengshanensis* Keng f. & T.P. Yi. , *B. fargesii* (E.G. Camus) Keng f. & T.P. Yi, and *B. aristata* Y. Ren, Y. Li & G.D. Dang resolved in a different, less well-supported clade that also included species from 4 other genera. They noted that the 'Alpine *Bashania* clade' in their study corresponded to *Arundinaria* subgenus *Sarocalamus* in the Flora of China (Li et al. 2006).

Li et al. (2013) later revised the Chinese species of *Arundinaria*, specifically in the context of their treatment in the Flora of China, in which species from *Bashania* and *Sarocalamus* had been included in *Arundinaria*. They decided that such treatment was not reasonable. In their revision they placed all 10 species in *Bashania*, and did not recognize *Sarocalamus*. They noted the disjunction in morphology, in ecology, and in placement on different clades in molecular studies of the two elements of *Bashania* as they were circumscribing it, and that the non-monophyly of *Bashania* raised some taxonomic problems. They looked forward to making a more credible revision of *Bashania* in the near future by adding further molecular sequences to their studies. However, such a revision has not yet been forthcoming.

One factor that could have caused legitimate concern when considering whether the Chinese species are congeneric with the type species of *Sarocalamus*, *S. racemosus*, is the disjunction between their recorded distributions. *S. racemosus* is found from the eastern border of Nepal to western Bhutan, while potential Chinese members of the genus are only known from Sichuan and Yunnan, on the very eastern fringes of the mountains of SW China.

While molecular studies are complex to undertake, and bamboo flowers may not be available for several decades, vegetative morphological characters can be assessed quickly and easily. Mid-culm branching characters are known to be very useful for separation of temperate Sino-Himalayan bamboo genera (Stapleton 1994), while differences between inflorescence characters are not as great as might be expected.

Material and methods

To clarify the morphological distinction between *Sarocalamus* and other genera and to investigate the association of the Himalayan type species *Sarocalamus racemosus* with the other putative congeneric species in China, branching patterns on living plants in western cultivation were inspected. To reveal the young branch initials and compare the branch complement structure, the sheath around mid-culm nodes was removed on young specimens from representatives of several genera encountered in these areas.

Results

The mid-culm branches of the Himalayan type species *Sarocalamus racemosus* were usually seen to have relatively long basal internodes, all bearing sheaths and branches at the nodes (Fig. 1a), only rarely showing a substantial degree of compression. Branch development was seen to be precocious, with persistent but thin sheathing. In the first year of growth, there is usually a very restricted number of branches at the node itself, essentially just one main branch with a subsidiary lateral enclosed in a large prophyll.

This arrangement is very similar to the pattern seen in *Phyllostachys* Siebold & Zucc., the only other Asian genus with elongated, uncompressed basal internodes on its branches, and nearly complete lateral branching. A young branch complement of *Phyllostachys atrovaginata* C.S. Chao & H.Y. Chou is portrayed in Fig. 1b. However, *Phyllostachys* species usually proceed to develop even longer internodes, as well as deeply sulcate culms and tough, rapidly deciduous sheaths.

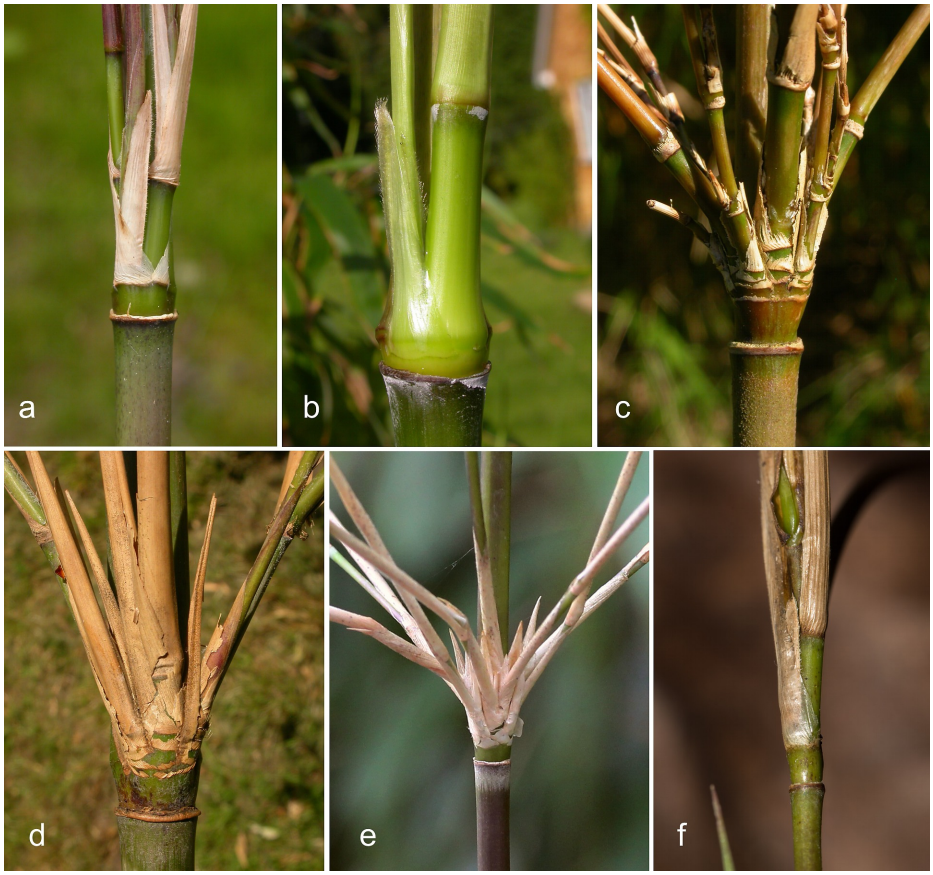

Figure 1. (a) *Sarocalamus racemosus*, young branching with nodal sheath removed. (b) *Phyllostachys atrovaginata*, young branching with nodal sheath removed. (c) *Yushania maling*, older branching showing multiple compressed internodes. (d) *Bashania fargesii* older branching showing multiple compressed internodes and tough persistent culm sheaths. (e) *Gelidocalamus stellatus*, showing multiple branches arising from compressed internodes. (f) Species from Dongchuan, Yunnan, young branching with nodal sheath removed. Photos: a, b, c, d, f Chris Stapleton; e Zhang Wen-Gen.

They also usually lack a basal lateral branch arising from the most basal lateral branch itself, giving the typical 2-branched complement by which *Phyllostachys* is so clearly recognizable.

In the mid-culm branch complement of all other bamboo genera found at high elevation in this region, several compressed (short) basal branch internodes are present and the norm, especially in *Fargesia* Franchet, *Borinda* Stapleton and *Yushania* Keng f., exemplified by *Yushania maling* (Gamble) R.B. Majumdar (Fig. 1c). Sheathing is incomplete where multiple lateral branches are found in close proximity in these 2 genera, the 2nd sheath on the central branch being absent (Stapleton 1994). These genera also differ from *Sarocalamus* in having pachymorph rhizomes.

In *Bashania fargesii* there are many heavily compressed basal internodes (Fig. 1d). As in *Sarocalamus* there is a full set of persistent sheaths at every node in *Bashania*, but the sheaths are all thick and tough. This pattern is similar to that seen in *Thamnocalamus*, another high altitude genus apparently restricted to the Himalayas, but well distinguished from the bamboos under consideration here, having pachymorph rather than leptomorph rhizomes, and partially bracteate inflorescences (Stapleton 1994).

Gelidocalamus has not been inspected first-hand in this study, but has been well illustrated elsewhere (*G. stellatus* in Nie et al., 2018), showing many compressed internodes and multiple branches at the mid-culm node, most of which do not rebranch, and a closer photo (Fig. 1e) reveals a complete set of sheaths.

The other genera that have leptomorph rhizomes and a restricted number of branches, such as *Indocalamus* Nakai, *Pseudosasa* Makino and *Arundinaria* all show some strongly compressed internodes between a variable number of sheathed nodes at the base of the central branch, these internodes usually bearing no lateral branches.

For comparison of a representative of the putative members of *Sarocalamus* from China with the Himalayan type species of *Sarocalamus*, *S. racemosus*, the mid-culm branching of a species of unclear specific identity from Dongchuan in N Yunnan, sent to the west by Prof Hsueh Ji-Ru in the 1970s under the unpublished name *Sinarundinaria parviflora*, is shown in Fig. 1f. It was collected south of the localities of *S. qiaojiaensis* and *S. spanostachyus*, and north east of the locality of *S. yongdeensis*. Branching characters clearly are very similar to those of *S. racemosus*, exhibiting all the distinctive features described

Table 1. Comparison of vegetative rhizome and branch complement characters for *Sarocalamus* and 7 other genera.

Genus	Rhizome	Compressed (short) branch internodes	Sheathing	Subsidiary branch development at all nodes of branches
Sarocalamus	leptomorph	rare	complete, persistent	complete
Phyllostachys	leptomorph	very rare	complete, deciduous	complete
Bashania	leptomorph	always present	complete, persistent	complete
Gelidocalamus	leptomorph	always present	complete, persistent	incomplete
Arundinaria	leptomorph	often present	complete, persistent	complete
Indocalamus & Pseudosasa,	leptomorph	usually present	complete, persistent	incomplete
Thamnocalamus	pachymorph	always present	complete, persistent	complete
Fargesia, Borinda, & Yushania	pachymorph	always present	incomplete, persistent	incomplete

above for that species: the long internodes, lateral branch development at all nodes, and a complete set of delicate but persistent sheaths. In addition the internodes are purple-spotted, smooth, terete, and glabrous, just as seen in *Sarocalamus racemosus*. This species has single leaf sheath oral setae similar to those seen in *S. spanostachyus*, but has glabrous rather than setose culm sheaths, and is much smaller, having similar stature to *S. qiaojiaensis* and *S. yongdeensis*.

The differences between the genera in rhizome form and branch complement characters are summarized in Table 1.

Discussion

From this morphological analysis it would appear that the branching characters are sufficient to delineate a discrete group of species, containing both the Himalayan type species of *Sarocalamus*, *S. racemosus* and also at least 1, and probably 5 similar species from SW China, despite the substantial gap in distribution. These characters are distinct from those of *Bashania*, *Gelidocalamus*, *Yushania*, *Borinda*, *Fargesia*, *Thamnocalamus*, *Indocalamus*, *Pseudosasa*, & *Arundinaria* and are closest to those of *Phyllostachys*. The scarcity of compressed branch internodes, together with the thin, persistent sheaths and consistent subsidiary branch presence at nodes are unique to the genus *Sarocalamus* among Asian temperate bamboos.

The published descriptions of the 3 species transferred into *Sarocalamus* here are sound, but they do not include a particularly detailed investigation of vegetative characters now known to be critical for generic placement, such as branch complement structure and sheathing, and their inflorescences are still unknown. However, the overall scarcity of branching and the persistence of the culm sheaths is consistent with *Sarocalamus* rather than other possible genera such as *Fargesia*, *Yushania*, or *Bashania*. Their high altitude ecological habitats associated with mountain tops and *Abies* forest also supports their inclusion in *Sarocalamus*. However, it is currently their placement in the well-supported 'Alpine *Bashania* clade' in molecular analyses (Zeng et al. 2010, Zhang et al. 2012) that provides the strongest evidence for their affinity to the genus *Sarocalamus*, which has recently been recognized in various accounts of bamboos and grasses (BPG 2012, Singh 2012, Kellogg 2015, Vorontsova et al. 2016).

Therefore it would now appear reasonable and credible to proceed with the transfer of the remaining species from the 'Alpine *Bashania* clade': *Bashania abietina*, *B. qiaojiaensis*, and *B. yongdeensis*, into *Sarocalamus*. As progressively more species are exported from China into western horticultural cultivation, hardy species such as these are requiring identification and more reliable taxonomy. A sound framework of recognisable genera and detailed exploration of their species boundaries and distribution patterns will also help in-situ conservation in their natural habitats.

Publication of these combinations in *Sarocalamus* and the illustrations of branching is intended to highlight the need for further investigation of their morphology, the provision of more comprehensive descriptions and illustrations to confirm generic identity, in-depth comparison with other species of the genus, as well as consideration of their conservation status. It is hoped that molecular analyses will also be continued to confirm their generic placement.

The large gap in the recorded distribution of *Sarocalamus* species between E Bhutan and Sichuan/Yunnan is probably due to inadequate bamboo fieldwork at high altitude in the relatively remote intervening areas of NE India and SW China. Indeed, the occurrence of such a species, the exact identity of which is unclear, has recently been reported in Menchuka, well to the west of Bhutan (Kandwal & Singh 2016). Future collectors should be made aware of the likelihood of their occurrence in these areas. Clearly there is a pressing need for more fieldwork to study the bamboos of SW China, NE India, and also NE Myanmar.

When studying and collecting alpine bamboos characters of generic importance need to be studied more closely, in order for them to be assigned to the correct genus. The inflorescences of *Sarocalamus* are ebracteate and paniculate, but with sparse pulvini and erect branches, bearing few, cylindrical spikelets. However, flowers are rarely available. Rhizomes are leptomorph, but need to be excavated for inspection. Branching characters are the easiest to inspect, but are usually overlooked. *Sarocalamus* branches at mid-culm nodes develop into distinctive branch complements, spreading into a fan or broom-shape, but only at a distance from the culm, arising from a central branch with limited compression of the basal internodes, the mechanism by which most other bamboos incorporate a larger number of branches into their complements.

Sarocalamus abietinus (T.P. Yi & Lin Yang) Stapleton comb. nov.
Basionym: *Bashania abietina* (T.P. Yi & Lin Yang, J. Bamboo Res. 17(4): 1 (1998).
Type: China. Sichuan Province, Mabian, Yaozishan, 2500--3200 m, 2 June 1998, T.P. Yi 98520 (holotype, SIFS)

This species is from Yaozishan in Sichuan, close to the type locality for *S. faberi*. It differs from that species in having falcate auricles on the culm sheaths and the leaf sheaths.

Sarocalamus qiaojiaensis (T.P. Yi & J.Y. Shi) Stapleton comb. nov.
Basionym: *Bashania qiaojiaensis* T.P. Yi & J.Y. Shi, J. Sichuan Forest. Sci. Technol. 28(4): 1. (2007).
Type: China. Yunnan, Qiaojia, Yaoshan, Maiping Village, Yaoshan, 3300--4000 m, 19 May 2007, T.P. Yi 07015 (holotype, SIFS).

Similar to *S. spanostachyus*, found on Yaoshan in NE Yunnan, close to the locality of *S. spanostachyus* on the other side of the Jinsha (Upper Yangtze) River in Sichuan. Compared to that species it has more leaf sheath oral setae, and it is smaller in stature.

Sarocalamus yongdeensis (T.P. Yi & J.Y. Shi) Stapleton comb. nov.
Basionym: *Bashania yongdeensis* T.P. Yi & J.Y. Shi, Forestry Res. 20: 864. (2007).
Type: China. Yunnan, Yongde, Daxue Shan, 3200 m, 23 September 2007, T.P. Yi 07022 (holotype, SIFS).

Also similar to *S. spanostachyus* but smaller, and apparently differing in having more leaf sheath oral setae, and found much further away, at 3,200–3,500 m on Daxue Shan in W Yunnan.

Tentative key to the described species of *Sarocalamus*

1 Culm sheath and leaf sheath auricles falcate..... *S. abietinus*
Culm sheath and leaf sheath auricles ovate, oblong or absent 2
2 Culms usually less than 1m tall..... 3
Culms usually more than 1m tall..... 4
3 Leaf sheath auricles small, leaf blades lanceolate *S. qiaojiaensis*
Leaf sheath auricles absent, leaf blades ovate-lanceolate.....
..... *S. yongdeensis*
4 Leaf sheath oral setae 1-2..... *S. spanostachyus*
Leaf sheath oral setae 3-8..... 5
5 Culm sheath oral setae prominent ..... *S. racemosus*
Culm sheath oral setae scarce..... *S. faberi*

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