Carex paracheniana (Carex sect. Rhomboidales, Cyperaceae), a New Species from Guangxi and Guizhou, China

Authors: Jin, Xiao-Feng, Simpson, David A., Zheng, Chao-Zong, Sun, Li, and Zhang, Hong-Wei

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Carex paracheniana (Carex sect. Rhomboidales, Cyperaceae), a New Species from Guanxi and Guizhou, China

Xiao-Feng Jin, 1,2,6 David A. Simpson, 3 Chao-Zong Zheng, 4 Li Sun, 1 and Hong-Wei Zhang 5

1 College of Life & Environmental Sciences, Hangzhou Normal University, 16 Xuelin Street, Xiasha Higher Educational District, Hangzhou 310036, China.
2 State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany, Chinese Academy of Sciences, Xiangshan, Beijing 100093, China.
3 Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AB, U. K.
4 College of Life Sciences, Zhejiang University, 388 Yuhangtang Road, Hangzhou 310058, China.
5 Zhejiang Qingliangfeng National Natural Reserve, 1 Tangchang Road, Lin’an 311321, China.
6 author for correspondence: docxfjin@163.com

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Abstract—Carex paracheniana, a new species of Cyperaceae from China, is described and illustrated. The new species is recognized as a member of Carex sect. Rhomboidales in having broadly ovoid perigynia and rhombic-ovoid nutlets. It is similar to C. cheniana and C. brevicuspis, but differs from the former in having narrower leaves 3–5 mm wide, staminate scales that are obtuse at the apex, and nutlets abruptly contracted into a ca. 1 mm long, slightly curved beak at the apex. It differs from C. brevicuspis in having ovate-elliptic pistillate scales that are glaucous or pale yellow and long-awned at the apex, and styles that are thickened at the base. Micromorphological characters of the leaf epidermis, perigynia, and nutlets are compared among taxa.

Keywords—Anatomy, Cyperaceae, nutlet, perigynium, SEM, taxonomy.

Carex L. is one of the largest genera of monocotyledons, and the largest in Cyperaceae, with ca. 1,800 species (Govaerts et al. 2007). It is easily distinguished from most other genera in the family by having the nutlets enclosed in sac-like perigynia (Nelmes 1951). It is currently divided into three subgenera, namely subg. Vignastra (Tucker.) Kük., subg. Vignea (B. Beauv. ex Lesti.) Peterm., and subg. Carex (Dai et al. 2000). It is almost cosmopolitan in distribution and found in a wide range of habitats (Dai et al. 2000; Nelmes 1951; Ohwi 1956; Zhang et al. 1998).

Kükenthal (1909) established Carex sect. Rhomboidales but without designating a type. Wang (1962) later designated the type as C. thibetica Franch. The section was distinguished by trigonous, obvoid or ovoid nutlets that are constricted in the middle, and mitrate or hastate at the apex (Kükenthal 1909). Ohwi (1936) and Akiyama (1955) also recognized sect. Rhomboidales but assigned taxa with non-beaked nutlets to other sections.

In the Flora of China, the treatment for Carex (Dai et al. 2000), the 54 species of sect. Rhomboidales sensu Kükenthal are divided between sect. Rhomboidales and sect. Careyanae Tucker. Species with densely-flowered spikes and nutlets that are often constricted at the middle are assigned to sect. Rhomboidales, while those with sparsely-flowered spikes and unconstricted nutlets are assigned to sect. Careyanae. In addition, the perigynia and nutlets of sect. Rhomboidales are distinct from those of sect. Careyanae. The perigynium beak in sect. Rhomboidales has a conspicuously bifid apex, while in sect. Careyanae it is obliquely truncate. The nutlets of sect. Rhomboidales (sensu Dai et al. 2000) are conspicuously beaked, with the beaks erect, slightly curved or coiled, and the styles frequently thickened at the base. In sect. Careyanae the nutlets are inconspicuously beaked, with non-thickened styles (Jin et al. unpublished). Recently, six new taxa have been described in sect. Rhomboidales (Jin et al. 2004; Jin and Zheng 2010; Oda et al. 2003; Shimizu 2008; Song et al. 2008; Su 2009).

In April 2004 and May 2009, the first author of this paper conducted fieldwork in the montane regions of eastern and southern China. During the fieldwork, an unusual Carex was collected from northern Guangxi which is recognized here as a new species in sect. Rhomboidales (sensu Dai et al. 2000), with morphological affinities to Carex cheniana Tang & F. T. Wang ex S. Yun Liang and C. brevicuspis C. B. Clarke.

Materials and Methods

Sampled Materials—Fieldwork was conducted in eastern, southern, and southwestern China, including Guangxi, Guizhou, Hunan, and Jiangxi provinces. The eight individuals of the new species were collected from Lingui County in Guangxi Zhuangzu Autonomous Region. In addition, 15 and 23 individuals of Carex cheniana Tang & Wang ex S. Yun Liang and C. brevicuspis C. B. Clarke, respectively, were sampled from Zhejiang.

Specimen Examination—Over 1,500 collections of sect. Rhomboidales were examined from 25 herbaria (ACM, E, GZTM, HAGS, HHBG, HIB, HNNU, HTC, HZU, IBK, IBSC, K, KUN, KYO, LBG, N, NAS, OSA, P, PE, SYS, TI, WUK, ZJFC, and ZM). Almost all the type specimens of the species in sect. Rhomboidales were available for study and comparison. Variation of morphological characters was evaluated from the collections examined, and the diagnostic characters among the new species, C. brevicuspis, and C. cheniana were compared as well.

Leaf Epidermis and Anatomy—The widest mature leaves of five individuals/sample of Carex brevicuspis, C. cheniana, and the new species were observed. For leaf epidermal studies, 2 cm long leaf sections of each sample were boiled in 1% NaOH solution for 30 minutes, and then rinsed in distilled water. The abaxial and adaxial pieces of epidermis were lightly scraped and released with
a stainless steel blade. They were stained in 1% safranin solution and dehydrated in an ethanol series, then mounted on microscope slides. The slides were examined and photographed with a Leica DM6000 microscope. For leaf anatomical studies, 5 mm long segments of each sample were boiled in water for 2 hr and rinsed in distilled water, then fixed in FAA for 24 hr. The fixed leaf segments were dehydrated, cleared, infiltrated, and embedded in an ethanol, xylen, paraffin oil, and paraffin series. Transverse sections were stained in 1% safranin and 0.5% fast green FCF (Zhang et al. 1998). The slides were again examined and photographed with a Leica DM6000 microscope.

Under the light microscope, cell and stomatal sizes of each species were randomly measured in a total of 100 cells that were from 20 slides of five individuals.

**Scanning Electron Microscopy (SEM) of Perigynia and Nutlets—** Mature perigynia were cleaned in 50% ethanol for 2 hr, and air dried. The cleaned perigynia were mounted on stubs using double-sided adhesive tape, and coated with a layer of gold. Mature nutlets were initially soaked in a solution of concentrated sulfuric acid and acetic anhydride (vol.: vol. = 1: 9) for 18 hr, then rinsed in acetic acid for 10 min and water for 5 min respectively, and placed in a bath-type ultrasonic cleaner for 30 min with 70% ethanol to remove the cuticle and outer periclinal wall of the epidermis (Oda et al. 2003). After air drying, the nutlets were mounted and coated in a similar manner to the perigynia. The coated perigynia and nutlets were observed and photographed using a XL-30E scanning electron microscope.

Perigynia and nutlets were randomly measured from different spikes of five individuals of each species for size measurements, with a total of 20 perigynia and nutlets being measured for each species.

**Results**

**Leaf Epidermis and Anatomy—** Leaf epidermal sections of Carex cheniana, C. brevicuspis, and the new species are shown in Fig. 1 and Table 1. The abaxial epidermal cells of the new species were oblong, with undulate anticlinal walls, while those of C. brevicuspis and C. cheniana had deeply undulate anticlinal walls. All the abaxial epidermal cells of C. cheniana had silica papillae. The new species and C. brevicuspis both had adaxial epidermal cells that were oblong, with deeply undulate anticlinal walls. The adaxial epidermal cells of C. cheniana were subquadrate but also had deeply undulate anticlinal walls.

Transverse sections of the leaves are shown in Fig. 2 and Table 1. The bulliform cells of C. cheniana were in two layers, while those of C. brevicuspis and the new species were in one layer. The sclerenchyma in the costae of the vascular bundles of C. cheniana was abaxially well developed, as it was in the lateral vascular bundles, both adaxially and abaxially. However, in C. brevicuspis and the new species it was less developed. The vascular bundles of C. cheniana had two cell layers, the inner one being sclerenchymatous, while in C. brevicuspis and the new species the bundles had only one, non-sclerenchymatous layer.

**SEM of Perigynia and Nutlets—** The perigynia are illustrated in Fig. 3. All were broadly ovoid, many-veined, sparsely pubescent, shortly stipitate at base, and abruptly beaked at the apex. The beak orifice was bifid, and the teeth of C. brevicuspis (0.798 ± 0.062 mm, mean ± standard deviation) were significantly longer than those of C. cheniana (0.553 ± 0.056 mm) and the new species (0.572 ± 0.032 mm) with a test of significance of group comparison. The p values respectively were 0.000362 and 0.000123. Nutlet shape and surface sculpturing in the three species are shown in Fig. 4. The nutlets were rhombic-ovoid, trigonous, with the three angles constricted at the middle, shortly curved stipitate at the base, with a beak at the apex. The epidermal cells of the nutlets of C. cheniana and C. brevicuspis were regularly 4–6-gonal, with slightly undulate inner periclinal walls. One or two silica bodies (central bodies) were present in each cell of C. brevicuspis, while only one silica body was present or silica bodies were absent in each cell of C. cheniana. The epidermal cells of the new species were regularly 4–6-gonal, and the inner periclinal walls were not undulate. A single silica body was present in each cell. With a test of significance of group comparison, the epidermal cells of the new species (42.253 ± 8.081 μm, mean ± standard deviation) were significantly smaller than those of C. cheniana (55.070 ± 10.522 μm) and C. brevicuspis (54.933 ± 10.956 μm), with the p values 0.000104 and 0.000313 respectively.

Table 1. Different characters of Leaf epidermis and anatomy in Carex paracheniana, C. cheniana and C. breviciusis (* Mean and standard deviation; ** Inner layer).

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Leaf epidermal characters</th>
<th>Leaf anatomy characters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adaxial epidermal cells</td>
<td>Abaxial epidermal cells</td>
</tr>
<tr>
<td>C. paracheniana</td>
<td>Oblong, Undulate</td>
<td>Deeply undulate</td>
</tr>
<tr>
<td>C. cheniana</td>
<td>Subquadrate</td>
<td>Deeply undulate</td>
</tr>
<tr>
<td>C. breviciusis</td>
<td>Oblong</td>
<td>Deeply undulate</td>
</tr>
</tbody>
</table>

Herbaceous perennial. Rhizome brownish-black, woody, thick, short, with many yellowish-brown, fibrous adventitious roots. Culms caespitose, central, 8–35 cm tall, trigonous, smooth, covered with purplish-brown fibrous sheaths at base. Leaves longer or equal to culms; leaf-blade 3–5 mm wide, flat, smooth on lower half, scabrous on upper margins; sheaths brown, fibribiform at apex. Involucral bracts leaf-like, shorter than inflorescence, sheathed; sheaths 0.5–1.5 cm long, obliquely truncate at orifice. Inflorescence paniculate, with 3–4 spikes; terminal spike staminate, cylindrical or clavate, yellowish-brown, 2–3 cm long, 2–2.5 mm wide, with a 2.5–4 cm long scabrous peduncle at base; lateral spikes pistillate, bearing a few staminate flowers at apex, cylindrical, 1–3 cm long, 7–9 mm wide, densely flowered, pedunculate; peduncles 1.5–3 cm long, slightly exerted from sheaths. Stamine scales ovate-oblong, pale brown, membranous, 4–4.5 mm long, 1.5–1.8 mm wide, obtuse at apex, green 3-veined costa on dorsal surface. Pistillate scales ovate-elliptic, 6.5–7 mm long (including awn), ca. 1.5 mm wide, glaucous or pale yellow, acuminate at apex, green 3-veined costa excurrent into a ca. 2 mm long scabrous awn. Perigynia broadly ovoid (excluding beak), 7–7.5 mm long, slightly longer than pistillate scales (including beak), ca. 3 mm wide, obliquely patent, obtusely trigonous, herbaceous, brownish-green, distinctly veined, sparsely pubescent on upper veins, abruptly contracted into a ca. 2 mm long beak at apex; beak sparsely pubescent at margin, orifice 2-lobed with short teeth. Stigmas 3; style thickened at base. Nutlets tightly enveloped by the perigynia, rhombo-oid, trigonous, 4.5–5 mm long (including beak), 2–2.5 mm wide, castaneous, with 3 angles constricted at middle, sides concave above and below, shortly curved, stipitate at base, abruptly contracted into a ca. 1 mm long cylindrical beak at apex, beak slightly curved, slightly annulate at orifice.

Figure 5: B, C and Figure 6.


Distribution and Habitat—Carex paracheniana is only known from two localities in southern China (Fig. 7). It grows in moist places under evergreen broad-leaved forest at 300–1,000 m (Fig. 5: A).

Phenology—Flowering and fruiting April-May.

Etymology—The specific epithet alludes to the morphological similarity of the new species to C. cheniana Tang & F. T. Wang ex S. Yun Liang.

Comments—The circumscription of sect. Rhomboideales by Ohwi (1936) excluded species with oblique beak orifices on the perigynia. Carex matsumurae was included in the section by Koyama (1962), Katsuyama (2005), and Hoshino and Masaki (2011), although it has perigynium beaks notched at the orifice, plano-convex nutlets, and...

two stigmas. These characters are different from those of other members of sect. *Rhomboidales*. Chang and Yang (1976) placed related species from northeastern China in two sections. The species with erect pistillate spikes and pubescent perigynia were placed in sect. *Rhomboidales*, while those with pendulous pistillate spikes and glabrous perigynia were placed in sect. *Laxiflorae* Kunth ex Mackenzie. Dai et al. (2000) also considered these two sections to identify the Chinese species of sect. *Rhomboidales*, but the name of sect. *Laxiflorae* was replaced by sect. *Careyanae* (Jin et al. 2011). Based on all species of sect. *Rhomboidales* in China and Japan, as well as by considering the characters of leaf anatomy, epidermis, perigynium and nutlet, we emend the circumscription of sect. *Rhomboidales* as follows:

Culms lateral or central; terminal spike staminate, lateral spikes androgynous, usually with a long or short staminate part at apex, or pistillate. Perigynia ovoid to broadly ovoid, trigonous, glabrous or pubescent, tenuously venose, apex contracted into a long beak, beak orifice

Fig. 4. SEM photographs of nutlets. A, B. *Carex paracheniana*. C, D. *C. cheniana*. E, F. *C. brevicaulis*. A, C, E. Whole view of nutlets. B, D, F. Surface sculpture.
Fig. 5. Photographs of Carex paracheniana. A. Natural habitat of the forest beside Baishi Village, Wnantian Township, Lingui County, Guangxi Zhuangzhu Autonomous Region, China. B. Habit. C. Spikes, terminal one staminate and lateral pistillate. Scale bar = 2 cm in Fig. 5B, 1 cm in Fig. 5C.
Nutlets contracted into a ca. 1 mm long, slightly curved beak at apex.

**C. paracheniana** is easily recognized as a member of sect. *Rhomboidales*, not only for the perigynium characters, but also for the nutlet morphology. It is similar to *C. cheniana* in having pale green leaves, and peristome scales that are glaucous or pale yellow, long-awned at the apex, but it differs in having 3–5 mm wide leaves, staminate scales that are obtuse at the apex, and nutlets contracted into a ca. 1 mm long, slightly curved beak at the apex. The new species also closely resembles *C. brevicuspis*, but differs by having ovate-elliptic peristome scales that are glaucous or pale yellow, and long-awned at apex and by styles that are thickened at base. Characters distinguishing the new species from related taxa are summarized in Table 2 and the key.

**Table 2. Morphological characters of Carex paracheniana, C. cheniana and C. brevicuspis**

<table>
<thead>
<tr>
<th>Characters</th>
<th>Carex paracheniana</th>
<th>Carex cheniana</th>
<th>Carex brevicuspis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culm height</td>
<td>8–35 cm</td>
<td>40–50 cm</td>
<td>20–55 cm</td>
</tr>
<tr>
<td>Leaf width</td>
<td>3–5 mm</td>
<td>5–9 mm</td>
<td>5–10 mm</td>
</tr>
<tr>
<td>Stamine scales</td>
<td>Ovate-oblong, obtuse at apex</td>
<td>Elliptic-lanceolate, long-awned at apex</td>
<td>Lanceolate, acuminate at apex</td>
</tr>
<tr>
<td>Pistillate scales</td>
<td>Brownish-green, pubescent</td>
<td>Yellowish-brown, pubescent</td>
<td>Dark-brown, sub-glabrous or sparsely pubescent</td>
</tr>
<tr>
<td>Perigynia</td>
<td>Contracted into a ca. 1 mm long, slightly curved beak at apex</td>
<td>Contracted into a ca. 1 mm long, slightly curved beak at apex</td>
<td>Contracted into a ca. 1 mm long, slightly curved beak at apex</td>
</tr>
</tbody>
</table>

**Key to Carex paracheniana and the Related Species of Sect. Rhomboidales in China**

1. Nutlet beaks slightly curved or erect, annulate at apex ........................................... 2
2. Perigynia densely pubescent; peristome scales, involucral bracts, bract sheaths, culms and leaves pubescent ............................. *C. pseudolaticeps* 
2. Perigynia sparsely pubescent or glabrous; peristome scales, involucral bracts, bract sheaths, culms and leaves glabrous 3
3. Perigynia pubescent; nutlets coiled-stipitate at base .................................................. 4
4. Lateral spikes androgynous, with a long staminate part at apex ................................ 5
5. Perigynia densely pubescent; peristome scales, involucral bracts, bract sheaths, culms and leaves pubescent ............................. *C. saxicola* 
5. Lateral spikes androgynous, with a long staminate part at apex ................................. *C. teinebrosa* 
6. Lateral spikes peristome, usually bearing a few staminate scales at apex .................. 6
7. Perigynia subcoriaceous, glaucous; nutlet beaks erect ............................................ 7
7. Perigynia herbaceous, brownish-green or dark brown; nutlet beaks slightly curved .......... 8
8. Perigynia brownish-green, pubescent on upper part; peristome scales ovate-elliptic, glaucous or pale yellow, apex long-awned; styles thickened at base ........................................ *C. paracheniana* 
8. Perigynia brownish-green, pubescent on upper part; peristome scales lanceolate, yellowish-brown, apex acuminate; styles not thickened at base ........................................ *C. brevicuspis* 
9. Perigynia glabrous; nutlets erect or coiled-stipitate at base ........................................ 9
10. Lateral spikes densely flowered, more than 20 flowers; peristome scales long-awned at apex ......................................................... 10
11. Nutlets long-beaked at apex, beaks erect ............................................................... 12
12. Nutlets not beaked, but disc-annulate at apex ......................................................... *C. rhyphophora* 
12. Nutlets not beaked, but disc-annulate at apex ......................................................... *C. cheniana* 
13. Lateral spikes peristome; nutlets deeply constricted on middle angles .................. 13
14. Spikes 4–7-flowered; peristome scales acuminate at apex ........................................ 14
15. Spikes 4–7, lateral ones androgynous; nutlets 3–5 mm long ...................................... *C. calcicola* 
15. Lateral spikes peristome; nutlets 2 mm long .......................................................... *C. liangii* 
16. Leaves 4–6 mm wide; culms 10–30 cm in height, slightly shorter than leaves ........... 16
17. Leaves 8–15 mm wide; culms 7–13 cm in height, far shorter than leaves .................. *C. camina* 
18. Leaves 8–15 mm wide; culms 7–13 cm in height, far shorter than leaves .................. *C. kaoi* 
18. Leaves 8–15 mm wide; culms 7–13 cm in height, far shorter than leaves .................. *C. harlandii* 
19. Perigynia reddish brown; nutlets coiled-stipitate at base; plants brown or reddish brown when dried ............................................. 19
20. Perigynia reddish brown; nutlets coiled-stipitate at base; plants brown or reddish brown when dried 20
1. Nutlet beaks coiled, not annulate at apex .......................................................... 15
15. Perigynia densely pubescent; pistillate scales, involucral bracts, bract sheaths, culms and leaves all pubescent .......................... C. laticeps
15. Perigynia pubescent or glabrous; pistillate scales, involucral bracts, bract sheaths, culms and leaves glabrous ....................... 16
16. Lateral spikes cylindrical-globose, 2–3 cm long, with peduncles enclosed in sheaths .......................................................... C. manca
17. Leaves 2–4 mm wide; nutlets constricted on one middle angle ........................................... C. jiuhuaensis
17. Leaves 6–10 mm wide; nutlets constricted on all middle angles ........................................... 18
18. Pistillate scales glaucous, long-awned at apex; staminate scales long-awned at apex ......................... C. cheniana
18. Pistillate scales pale yellow, acuminate or short-awned at apex; staminate scales acuminate at apex ......................... 19
19. Lateral spikes 12–15 mm wide; leaves 12–18 mm wide .................................................. C. nanjaensis
19. Lateral spikes 7–10 mm wide; leaves 3–10(–17) mm wide .................................................. 20
20. Lateral spikes with a long staminate part at apex, the staminate part equal to the pistillate part .......................... 21
21. Perigynia pubescent, with a 2.5–3 mm long beak at apex, horizontally patent at maturity ....................... C. hibbertica
21. Perigynia glabrous, with a ca. 4 mm long beak at apex, horizontally patent at maturity ....................... C. kuchuenensis
22. Leaves 7–10(–17) mm wide; perigynia horizontally patent at maturity ................................ C. heudesii
22. Leaves 3–7 mm wide; perigynia obliquely patent at maturity .............................................. C. basiflora

Acknowledgments. This work was supported by the National Natural Science Foundation of China (Grants No. 31170183, 30870150), and the project of State Key Laboratory of Systematic and Evolutionary Botany (Grant No. LSEB2011-04). We are most grateful to Professors LIANG Song-Yun and DAI Lun-Kai for their kind help and continuous encouragement, to Professor WANG Wen-Tsai for modifying the draft, to the curators of ACM, E, GZTM, HAGS, HHBG, HIB, HNNU, HTC, HZU, IBK, IBSC, K, KUN, KYO, LBG, N, NAS, OSA, P, PE, SYS, TI, WUK, ZJFC, and ZM for permitting the first author to visit their herbaria.

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