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

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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. *Vigneastra* (Tucker.) Kük., subg. *Vigneia* (B. Beauv. ex Lest.) 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, obovoid 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* T. 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, HACS, 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, xylene, 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 \pm 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 μ m, mean \pm standard deviation) were significantly smaller than those of *C. cheniana* (55.070 ± 10.522 μ m) and *C. brevicuspis* (54.933 ± 10.956 μ m), with the *p* values 0.000104 and 0.000313 respectively.

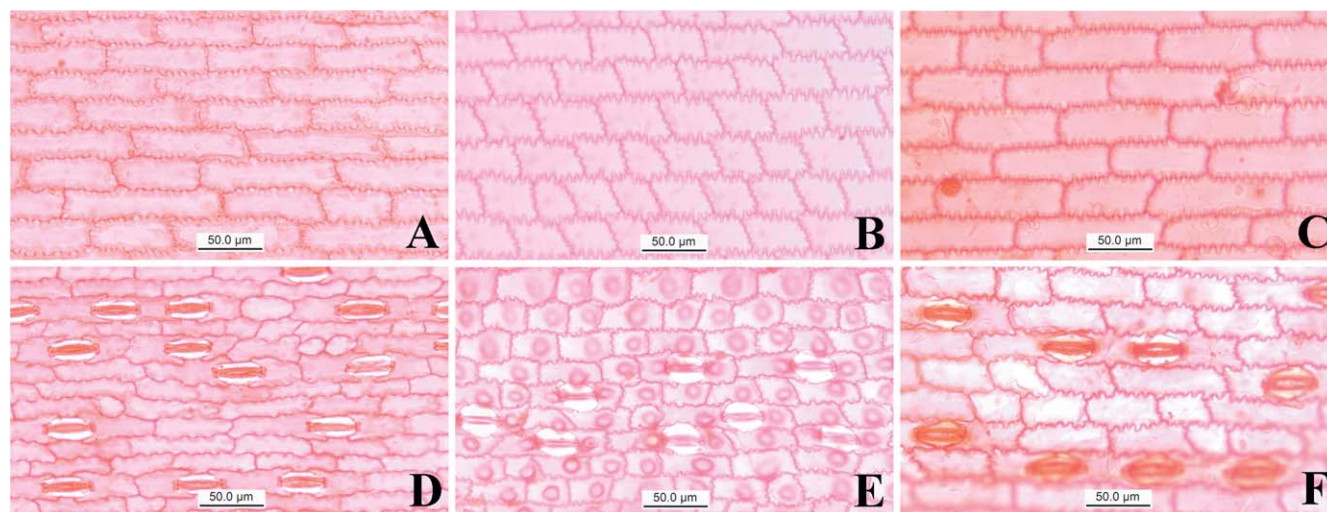


FIG. 1. Light microscope photographs of leaf epidermis. A, D. *Carex paracheniana*. B, E. *C. cheniana*. C, F. *C. brevicuspis*. A, B, C. Adaxial epidermis. D, E, F. Abaxial epidermis.

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

Taxon	Leaf epidermal characters					Leaf anatomy characters				
	Adaxial epidermal cells			Abaxial epidermal cells		Cell layer of bulliform cells	Size (μm)	Sclerenchyma in costae	Sclerenchyma in lateral veins	Cell layers of vascular bundles
	Shape	Anticlinal wall	Size (μm)	Shape	Anticlinal wall					
<i>C. paracheniana</i>	Oblong	Deeply undulate	86.6 ± 10.3 × 25.2 ± 3.7*	Oblong	Undulate	One	24.6 ± 5.0 × 34.5 ± 7.1	Well developed abaxially	Well developed adaxially and abaxially	One
<i>C. cheniana</i>	Subquadrate	Deeply undulate	46.5 ± 7.9 × 30.4 ± 4.3	Oblong	Deeply undulate	Two	42.6 ± 11.6 × 120.5 ± 23.7; 19.7 ± 6.4 × 52.4 ± 11.3**	Well developed adaxially and abaxially	Well developed adaxially and abaxially	Two
<i>C. brevicuspis</i>	Oblong	Deeply undulate	75.4 ± 18.6 × 24.9 ± 4.0	Oblong	Deeply undulate	One	19.6 ± 5.6 × 36.7 ± 6.9	Well developed abaxially	Well developed adaxially and abaxially	One

TAXONOMIC TREATMENT

Carex paracheniana X. F. Jin, D. A. Simpson & C. Z. Zheng, sp. nov.—TYPE: CHINA. Guangxi Zhuangzu Autonomous Region: Lingui County, Wantian Township, Baishi Village, roadside on slope, 110°04'33.86''(E), 25°39'13.26'' (N), alt. 800 m, 22 Apr 2004 (fl., fr.), X. F. Jin 947 (holotype: HTC!; isotypes: HZU!, ZM!).

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, fibriform 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 exserted from sheaths. Staminate 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, rhombic-ovoid, 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.

Representative Specimens Examined—CHINA. Guangxi Zhuangzu Autonomous Region: Lingui County, Wantian Township, Baishi Village, on slope, alt. 1,000 m, 22 Apr 2004, X. F. Jin 943 (PE); the same locality, under forest, alt. 550 m, 14 May 2009, X. F. Jin 2379 (HTC, ZM), 2380 (HTC, HZU). Guizhou: Pingba County, Chaotian, on slope, alt. 1,440 m, 11 Apr 1987, Pingba Exped. 380 (GZTM).

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 500–1,000 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. *Rhomboidales* 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

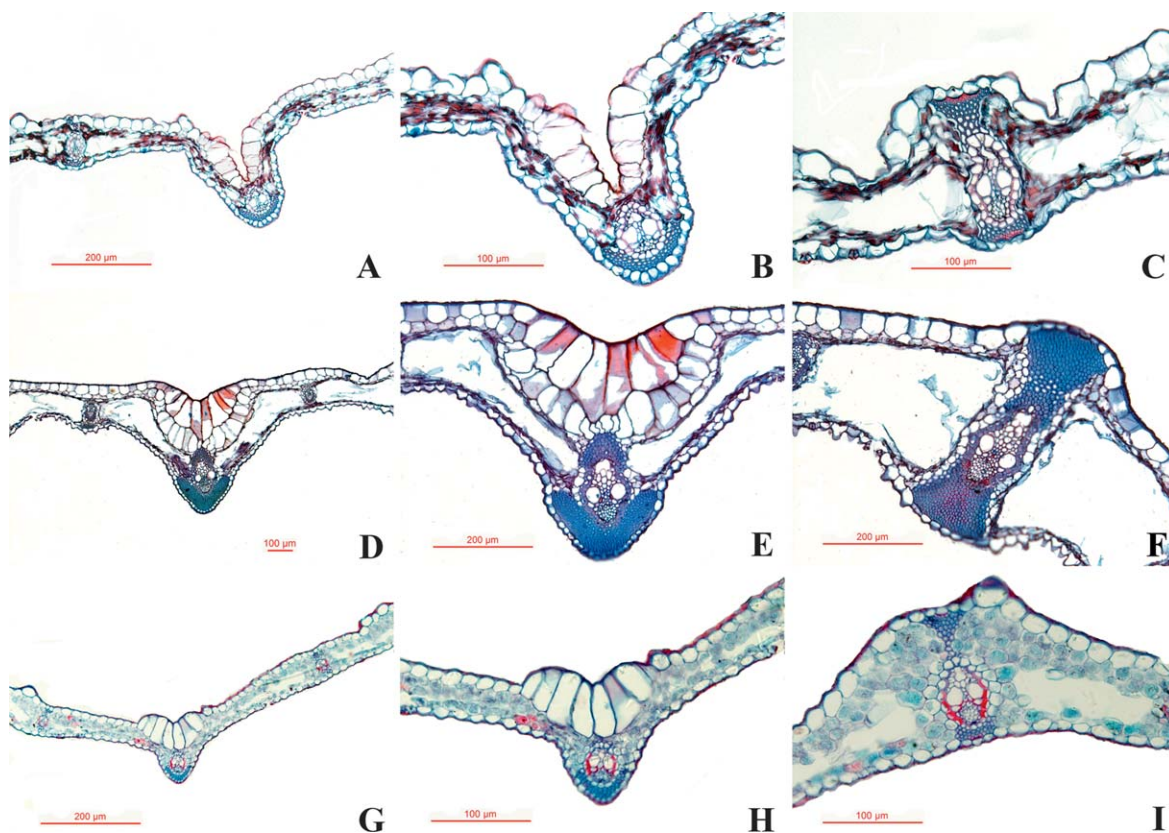


FIG. 2. Light microscope photographs of leaf anatomy. A-C. *Carex paracheniana*. D-F. *C. cheniana*. G-I. *C. brevicuspis*. A, D, G. Central part of transverse section. B, E, H. Vascular bundle of costa and bulliform cells. C, F, I. Vascular bundle of lateral veins.

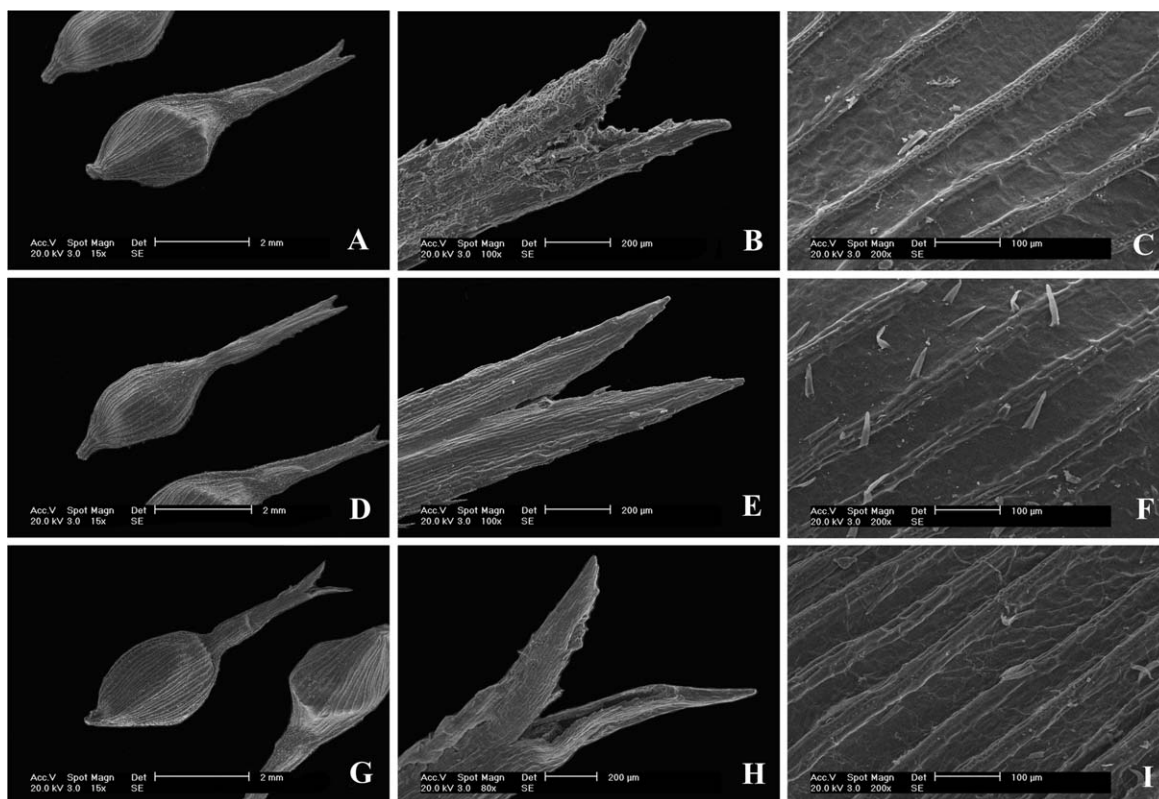


FIG. 3. SEM photographs of perigynia. A-C. *Carex paracheniana*. D-F. *C. cheniana*. G-I. *C. brevicuspis*. A, D, G. Whole view of perigymia. B, E, H. Short teeth of perigynia. C, F, I. Sculpture and indumentum of perigynium bodies.

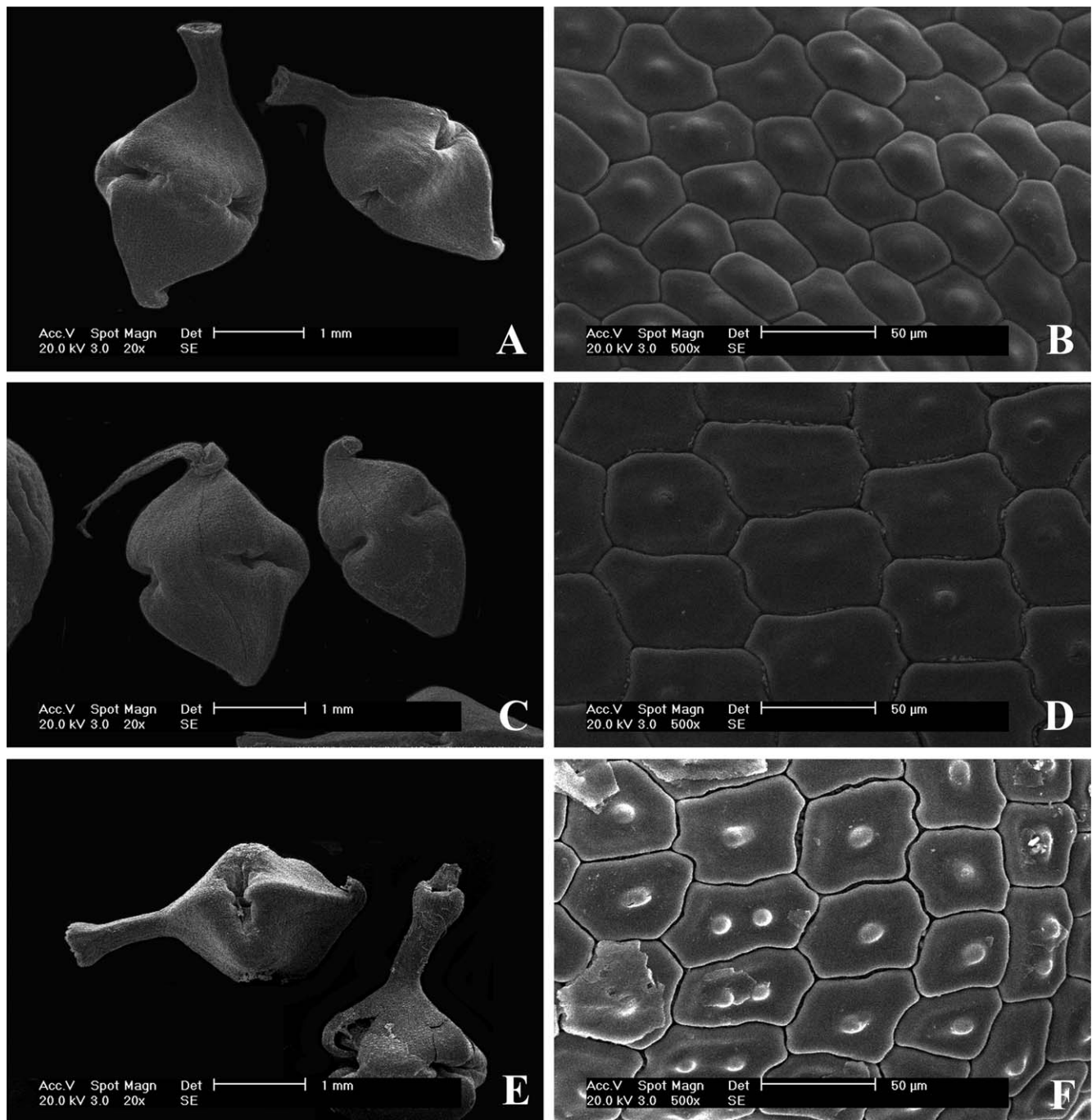


FIG. 4. SEM photographs of nutlets. A, B. *Carex paracheniana*. C, D. *C. cheniana*. E, F. *C. brevicuspis*. A, C, E. Whole view of nutlets. B, D, F. Surface sculpture.

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

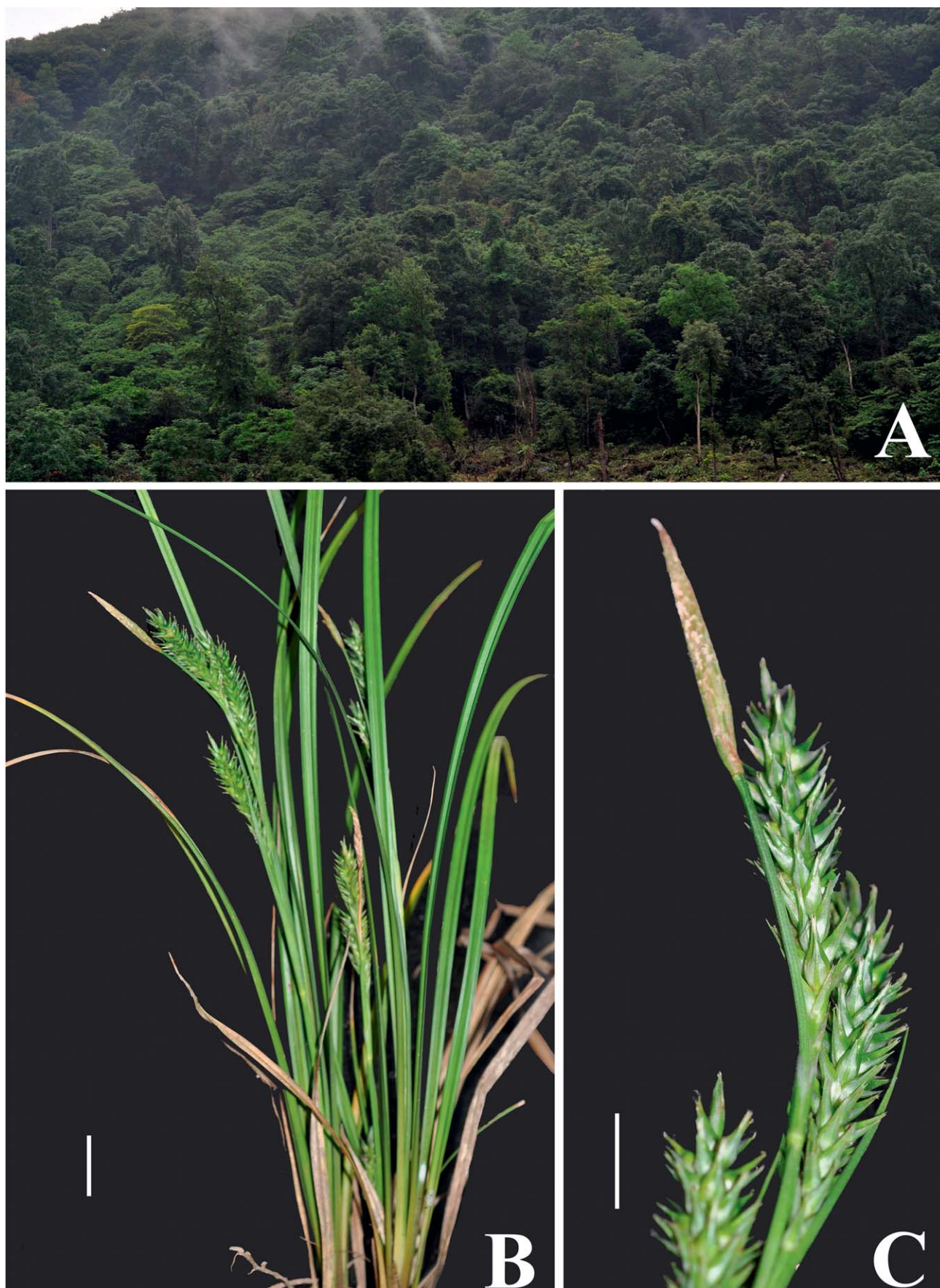


FIG. 5. Photographs of *Carex paracheniana*. A. Natural habitat of the forest beside Baishi Village, Wantian Township, Lingui County, Guangxi Zhuangzhu Autonomous Region, China. B. Habit. C. Spikes, terminal one staminate and lateral pistillate. Scale bar = 2 cm in Fig. 5B, 1 cm in Fig. 5C.

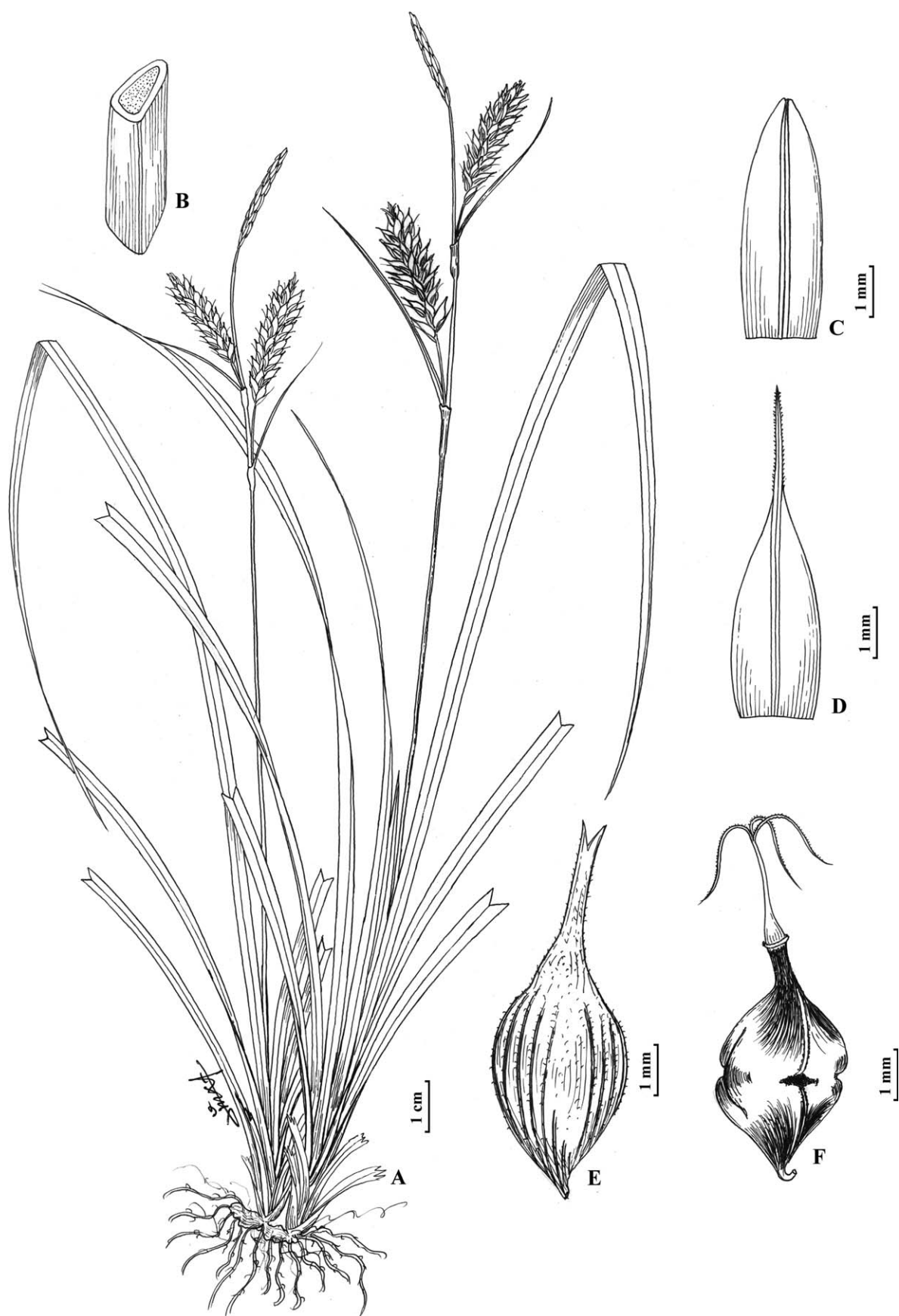


FIG. 6. *Carex paracheniana* X. F. Jin, D. A. Simpson & C. Z. Zheng, sp. nov. A. Habit. B. Transverse section of culm. C. Staminate scale. D. Pistillate scale. E. Perigynium. F. Nutlet. All from X. F. Jin 947.

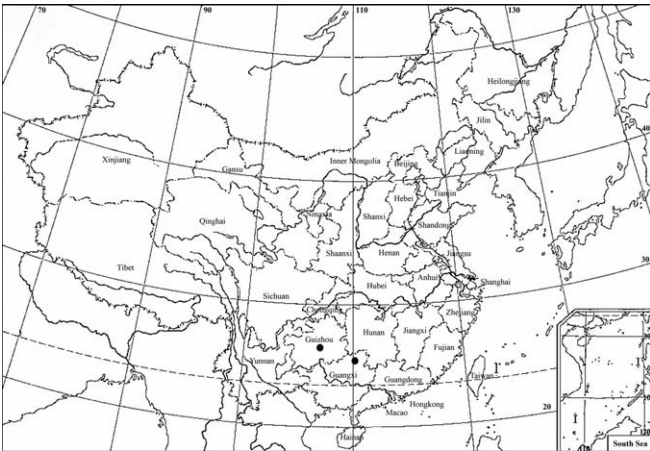


FIG. 7. Geographical distribution of *Carex paracheniana* X. F. Jin, D. A. Simpson & C. Z. Zheng in Guangxi and Guizhou, southern China.

bifid. Stigmas 3; style thickened or not at base. Nutlets rhombic-ovoid, rarely obovoid or broadly obovoid, trigonous, constricted at middle angles, rarely not constricted, with a conspicuous beak or disc-annulate at apex, beak erect, slight curved or coiled.

Carex 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 pistillate 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 pistillate 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*

Characters	<i>C. paracheniana</i>	<i>C. cheniana</i>	<i>C. brevicuspis</i>
Culm height	8–35 cm	40–50 cm	20–55 cm
Leaf width	3–5 mm	5–9 mm	5–10 mm
Length of staminate spikes	2–3 cm	1–2.5 cm	2.5–4 cm
Length of pistillate spikes	1–3 cm	3.5–6 cm	3.5–7 cm
Staminate scales	Ovate-oblong, obtuse at apex	Elliptic-lanceolate, long-awned at apex	Lanceolate, acuminate at apex
Pistillate scales	Ovate-elliptic, glaucous or pale yellow, long-awned at apex	Narrowly ovate, glaucous, long-awned at apex	Lanceolate, yellowish brown, acuminate at apex
Perigynia	Brownish-green, pubescent on upper part	Yellowish-brown, pubescent	Dark-brown, sub-glabrous or sparsely pubescent
Nutlets	Contracted into a ca. 1 mm long, slightly curved beak at apex	Contracted into a coiled beak at apex	Contracted into a ca. 1 mm long, slightly curved beak at apex

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; pistillate scales, involucre bracts, bract sheaths, culms and leaves pubescent *C. pseudolaticeps*
- 2. Perigynia sparsely pubescent or glabrous; pistillate scales, involucre 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. Pistillate scales ovate-lanceolate, pale yellow, apex acuminate, with a ca. 2 mm long scabrous awn *C. saxicola*
- 5. Pistillate scales elliptic, brown, apex emarginate, with a 3–4 mm long scabrous awn *C. tenebrosa*
- 4. Lateral spikes pistillate, usually bearing a few staminate flowers at apex 6
- 6. Rhizomes long-creeping; leaves trabeculate; pistillate scales with a glabrous awn at apex *C. yandangshanica*
- 6. Rhizomes short; leaves not trabeculate; pistillate scales with a scabrous awn at apex, or acuminate 7
- 7. Perigynia subcoriaceous, glaucous; nutlet beaks erect *C. chaofangii*
- 7. Perigynia herbaceous, brownish-green or dark brown; nutlet beaks slightly curved 8
- 8. Perigynia brownish-green, pubescent on upper part; pistillate scales ovate-elliptic, glaucous or pale yellow, apex long-awned; styles thickened at base *C. paracheniana*
- 8. Perigynia dark brown, sparsely pubescent or subglabrous; pistillate scales lanceolate, yellowish-brown, apex acuminate; styles not thickened at base *C. brevicuspis*
- 3. Perigynia glabrous; nutlets erect or coiled-stipitate at base 9
- 9. Pistillate scales glaucous or pale yellow; nutlets erect-stipitate at base; plants yellowish-green when dried 10
- 10. Lateral spikes densely flowered, more than 20 flowers; pistillate scales long-awned at apex 11
- 11. Lateral spikes androgynous, with a long staminate part at apex; nutlets shallowly constricted on middle angles 12
- 12. Nutlets long-beaked at apex, beaks erect *C. rhynchophora*
- 12. Nutlets not beaked, but disc-annulate at apex *C. chorda*
- 11. Lateral spikes pistillate; nutlets deeply constricted on middle angles *C. harlandii*
- 10. Lateral spikes 4–7-flowered; pistillate scales acuminate at apex 13
- 13. Leaves 4–6 mm wide; culms 10–30 cm in height, slightly shorter than leaves *C. canina*
- 13. Leaves 8–15 mm wide; culms 7–13 cm in height, far shorter than leaves *C. kaoi*
- 9. Pistillate scales reddish brown; nutlets coiled-stipitate at base; plants brown or reddish brown when dried 14
- 14. Spikes 4, lateral spikes pistillate; nutlets 2 mm long *C. liqingii*
- 14. Spikes 4–7, lateral ones androgynous; nutlets 3–3.5 mm long *C. calcicola*

1. Nutlet beaks coiled, not annulate at apex 15
15. Perigynia densely pubescent; pistillate scales, involucre bracts, bract sheaths, culms and leaves all pubescent *C. laticeps*
15. Perigynia pubescent or glabrous; pistillate scales, involucre bracts, bract sheaths, culms and leaves glabrous 16
16. Lateral spikes cylindrical-globose, 2–3 cm long, with peduncles enclosed in sheaths 17
17. Leaves 6–10 mm wide; nutlets constricted on all middle angles *C. manca*
17. Leaves 2–4 mm wide; nutlets constricted on one middle angle *C. jiuhuaensis*
16. Lateral spikes cylindrical, 3–6 cm long, with peduncles exerted from sheaths 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. nanchuanensis*
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, obliquely patent at maturity *C. tibetica*
21. Perigynia glabrous, with a ca. 4 mm long beak at apex, horizontally patent at maturity *C. kuchunensis*
20. Lateral spikes with a short staminate part at apex, the staminate part rather shorter than the pistillate part 22
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*

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