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First description of carposporophyte development in *Scinaia chinensis* (Galaxauraceae, Rhodophyta), a species newly recorded for Taiwan

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Abstract – *Scinaia chinensis* (Tseng) Huisman, a little-known member of the Galaxauraceae, was recently collected from northeastern Taiwan. The carposporophyte development of this species is documented in detail and its taxonomic position is discussed. Colourless utricle cells are present in the cortex of older branches and 1-2 pigmented spherical monosporangia arise terminally from stalk-like outer cortical cells. Carpogonial branches consist of three cells: the carpogonium bearing a long trichogyne, the hypogynous cell bearing two one-two celled sterile branches, and the basal cell. After presumed fertilization, the basal cell produces 4-5 sterile branches that grow to form an involucre/pericarp. The fertilized carpogonium cuts off two gonimoblast initials, which develop further radially. The pit plugs between hypogynous cell, basal cell and inner gonimoblast cells break down and a large fusion cell forms at the base of the carposporophyte at maturity. After comparing *Scinaia chinensis* to other species of *Gloiophloea* and *Scinaia*, we conclude that it is well distinguished from *Gloiophloea* and displays closer affinities to the members of *Scinaia*, based on the presence of colorless utricles and the fact that there are only two sterile branches borne on the hypogynous cell. These observations, therefore, support the transfer of *Gloiophloea chinensis* Tseng to *Scinaia chinensis* (Tseng) Huisman.

Galaxauraceae / *Gloiophloea chinensis* / Nemaliales / New record / *Scinaia chinensis* / Taiwan

Résumé – **Première description du développement du carposporophyte de *Scinaia chinensis* (Galaxauraceae, Rhodophyta), espèce nouvellement récoltée à Taiwan.** *Scinaia chinensis* (Tseng) Huisman, une espèce peu connue des Galaxauraceae, a été récemment récoltée dans la région nord-est de Taiwan. Le développement du carposporophyte est décrit en détail et la position taxinomique de cette espèce est discutée. Des cellules incolores en forme d'utricule sont présentes dans le cortex des rameaux les plus agés et des monosporocystes à 1-2 cellules pigmentées se développent à l'extrémité des cellules corticales externes de forme allongée. Les rameaux carpogoniaux sont constitués de 3 cellules : le carpogone portant un long trichogyne, les cellules sous-carpogoniales portant deux rameaux stériles à une ou deux cellules et la cellle basale. Après la fécondation présumée,

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la cellule basale produit 4-5 rameaux stériles qui, en se développant, forment un involucre/péricarpe. Le carpogone fécondé se divise en deux initiales de gonimoblastes qui se développent ensuite de façon radiale. Les bouchons synaptiques entre les cellules sous-carpogoniales, la cellule basale et les cellules internes du gonimoblaste disparaissent et, à maturité, une grande cellule de fusion se forme à la base du carposporophyte. Après avoir comparé *Scinaia chinensis* avec les autres espèces de *Gloiophloea* et *Scinaia*, nous concluons que cette espèce est bien distincte de *Gloiophloea* et présente de plus étroites affinités avec les autres espèces de *Scinaia*, en raison de la présence d'utricules incolores et du fait qu'il y a seulement deux rameaux stériles se formant sur les cellules sous-carpogoniales. En conséquence, ces observations confortent le transfert de *Gloiophloea chinensis* Tseng en *Scinaia chinensis* (Tseng) Huisman. (Traduit par la Rédaction)

Galaxauraceae / *Gloiophloea chinensis* / Nemaliales / Nouvelle signalisation / *Scinaia chinensis* / Taiwan

INTRODUCTION

The family Galaxauraceae contains four non-calcified genera, *Gloiophloea* J. Agardh (1872), *Scinaia* Bivona-Bernardi (1822), *Nothogenia* Montagne (1843) and *Whidbeyella* Setchell *et* Gardner (1903), distributed from warm waters to temperate oceans. With the possible exception of *Whidbeyella* (Scagel, 1962), a genus in need of re-examination, the gonimoblast initials are cut off directly from the zygote (= post fertilization carpogonium) (Huisman & Womersley, 1994). *Scinaia* differs from *Gloiophloea* in having colourless utricles in the outer cortex (Huisman, 1985), and from *Nothogenia* in having chains of carposporangia and in the habit of the tetrasporophyte (Anderson & Stegenga, 1985; Huisman, 1987; Huisman & Womersley, 1992).

The "*Scinaia* assemblage" (Setchell, 1914) originally consisted of four genera: *Scinaia*, *Gloiophloea*, *Pseudoscinaia* Setchell (1914), and *Pseudogloiophloea* Levring (1953). In a re-examination of this assemblage, Huisman (1985) concluded that only two genera, *Scinaia* and *Gloiophloea*, were worth recognizing. *Scinaia* was erected by Bivona-Bernardi (1822) with the single species *S. forcellata* Bivona-Bernardi and was based on materials cast ashore near Palermo and Naples. The genus currently includes approximately 38 species, with a worldwide distribution ranging from tropical to cold-temperate oceans (for all currently accepted names see Guiry & Nic Dhonncha, 2003).

The genus *Gloiophloea* was established by J. Agardh (1872) with the single species *G. scinaioides*, from Western Port, Victoria, southern Australia. In the past some 12 species have been attributed to the genus (see Table 1), but Huisman (1985) and Huisman & Womersley (1994) recognize only three species, *G. articulata* Weber-van Bosse, *G. rosea* (J. Agardh) Huisman *et* Womersley, and *G. scinaioides*, the remainder being removed to the genus *Scinaia*. Of the recognized species, reproduction is unknown in *G. articulata* and the taxonomic status of this entity is doubtful (Huisman, 1986; Guiry & Nic Dhonncha, 2003).

Some of the transfers to *Scinaia* made by Huisman (1985) were based on descriptions in the literature and actual specimens were not examined (Huisman, personal communication). This is true of *Scinaia chinensis*, the species examined herein. When Tseng (1941) first described *Gloiophloea chinensis*, virtually nothing was known about its reproductive structures. He illustrated the surface view and

Table 1. Species attributed to *Gloiophloea*. Those in bold are presently accepted.

Species	*Type locality*
G. scinaioides J. Agardh (1872) (the type)	Western Port, Victoria, southern Australia
G. capensis Setchell (1914)	Port Alfred, Cape Proviance, South Africa
G. confusa Setchell (1914)	Victoria, British Columbia to San Pedro, California
G. halliae Setchell (1914)	St. Lucie, Florida
G. okamurae (as *okamurai*) Setchell (1914)	Enoshima, Japan
G. undulata (Montagne) Setchell (1914)	The coasts of Chili and Peru
G. articulata Weber-van Bosse (1914)	Cargados Carajos, Mascarene Group, Indian Ocean
G. fascicularis Børgesen (1934)	Port Okha, Gujarat, India
G. chinensis Tseng (1941)	Tsinglan-Kang, Wenchang, Hainan Islnad, China
G. caribaea Taylor (1942)	Haiti
G. verae Dickinson (1951)	The Gold Coast, Australia
G. rosea (J. Agardh) Huisman *et* Womersley (1994)	Port Philip Heads, Victoria, southern Australia

a transverse section of the frond, showing moniliform rows of cortical cells and the presence of colorless utricle cells, but no details of cystocarp development were given.

Our recent collections from northern Taiwan included some cystocarpic specimens of *S. chinensis*. In this study, the pre- and post-fertilization events are documented in detail for the first time and the taxonomic affinities of the species are discussed.

MATERIALS AND METHODS

Algal samples were collected by snorkeling from Lungtung Bay, northeastern Taiwan (25°06.38”N, 121°54.749”E). Specimens for morphological study were fixed in 10% formalin/seawater, then stored in 5% formalin/seawater or pressed on herbarium sheets. Voucher specimens were deposited in the Department of Biology, National Changhua University of Education, Taiwan. Hand sections were stained with 1% aniline blue and post-fixed with 1% HCl, then mounted in a drop of 50% Karo™ corn syrup (Tsuda & Abbott, 1985). Drawings were made with the aid of camera lucida, and photomicrographs were taken on a Zeiss light microscope through a cool CCD system (Pixera Penguin 600CL compiled with Automontage Software, Pixera Company, CA, USA).

RESULTS

Scinaia chinensis (Tseng) Huisman 1985, p. 417, table 1

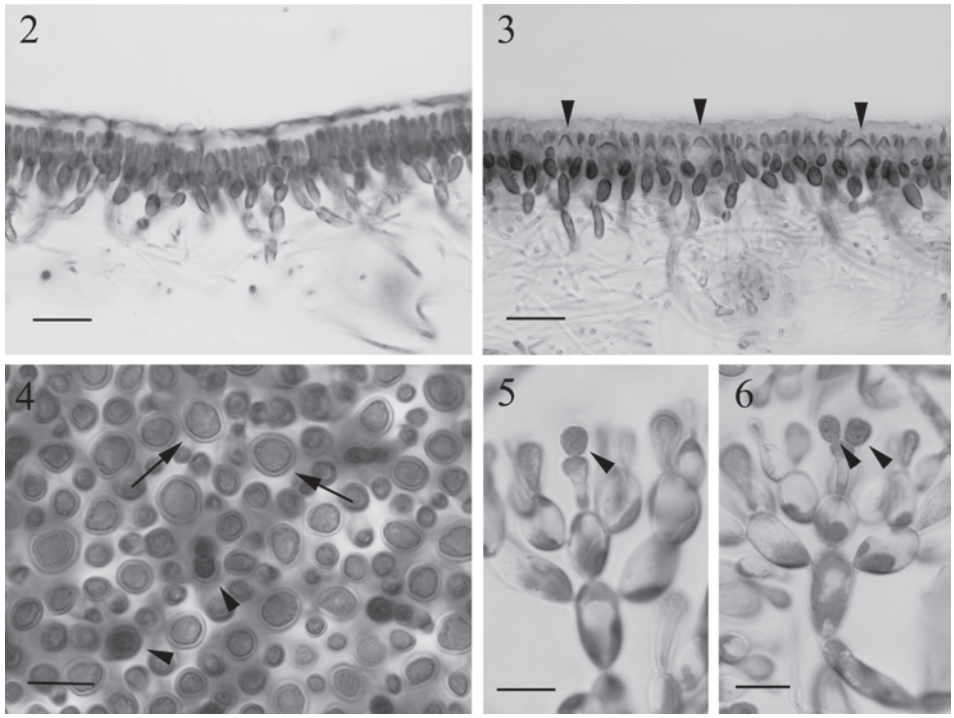
Basionym: *Gloiophloea chinensis* Tseng 1941, pp. 110-114, pl. X; Tseng 1983, p. 64, pl. 34, fig. 3.
Homotypic synonym: *Pseudogloiophloea chinensis* (Tseng) Papenfuss 1968, p. 280.

Fig. 1. Habit of female gametophyte of *Scinaia chinensis* (Tseng) Huisman (Lungtung Bay, Northeastern Taiwan). Scale bar = 10 mm.

Distribution: Tsinglan-Kang, Wenchang, Hainan Islnad, China (type locality); Lungtung Bay, Taiwan (25°06.38”N, 121°54.749”E).
Habitat and seasonality: Collections were made in April, 2002, February, 2003 and April, 2003. Plants grew seasonally in spring and winter, mainly at 0.5 to 3 m depths where they were abundant on rocks or sometimes on rocky substratum with a slight covering of sand.
Examined specimens: Lungtung Bay, northeastern Taiwan; *coll. S.-L. Liu & C.-S. Lin*, 24.iv.02, SLL91042401, female; *coll. S.-L. Liu & W.-L. Wang*, 25.i.03, SLL92022501, female; *coll. S.-L. Liu & C.-C. Liao*, 19.iv.03, SLL92041901, female.

Habit and vegetative morphology

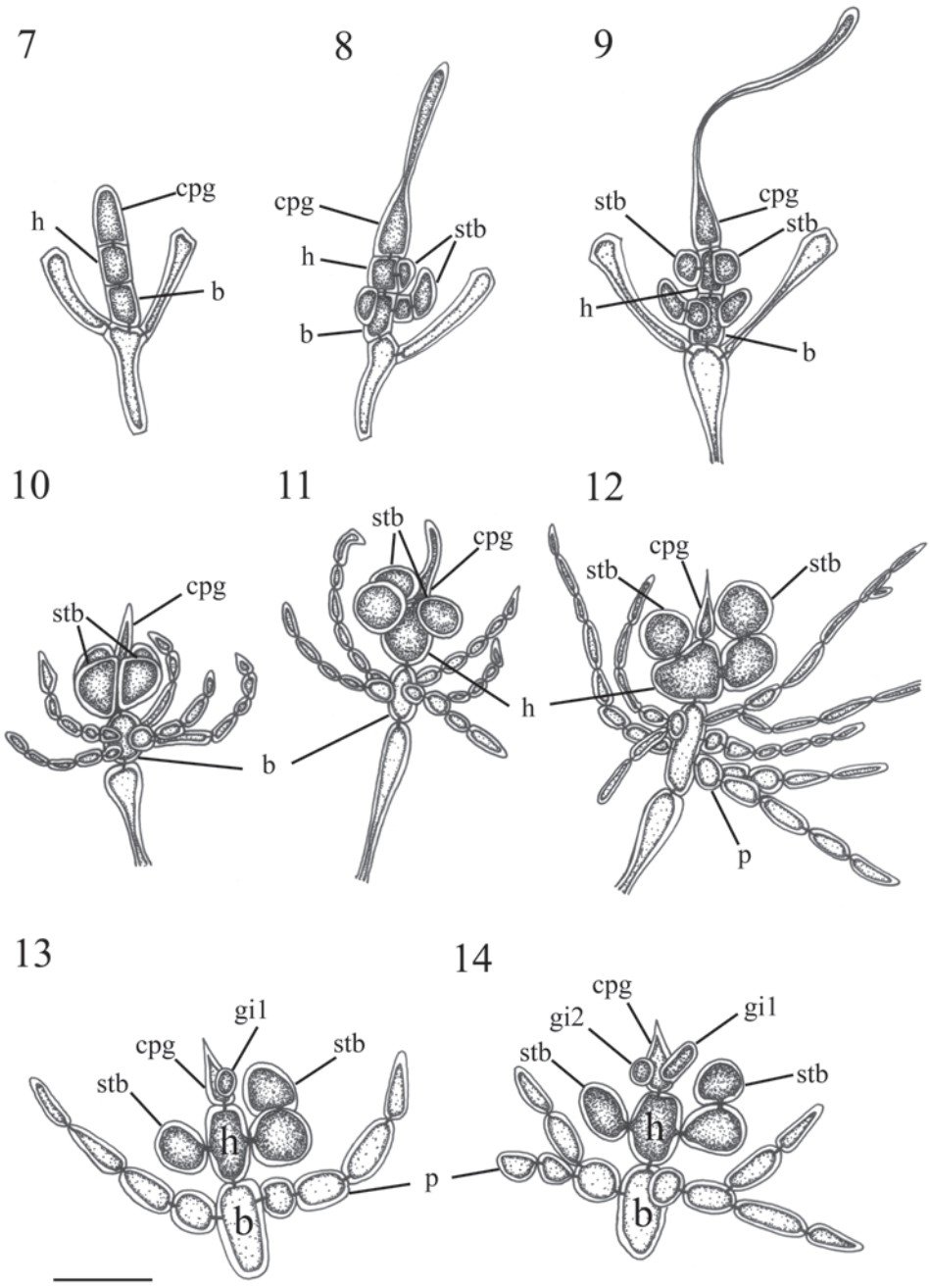
Gametophytic thalli (Fig. 1) are cylindrical, cartilaginous to mucilaginous, 3-5 cm in height and arise from a small discoid holdfast attached to rocks. Erect branches are dichotomous, unconstricted, and consist of six to seven times furcated branches. Distances between furcations are 4-8 mm. Branches segments are 1-1.5 mm wide and 4-7 mm long (Fig. 1). Growth is multiaxial, with a medullary core of numerous, slender branched filaments, 2.5-12.5 μm in diameter (Figs 2, 3). The cortex structure in young branches is *Gloiophloea*-like in having moniliform cortical cell with no obvious large colourless utricles (Fig. 2), then become two to four celled layers, 70-90 μm in thickness, with an outer layer of colourless utricles, 17.5-25 long and 20-25 μm in diameter (Fig. 3), these surrounded by numerous smaller colourless cells, 5-10 μm in diameter (Fig. 4).



Figs 2-6. Cortex and monosporangia of *Scinaia chinensis* (Tseng) Huisman. **2.** Transverse section of cortex from young gametophyte showing *Gloiophloea*-like structure without colorless utricle cells. **3.** Transverse section of cortex from an older gametophyte showing large colorless utricle cells (arrowheads). **4.** Surface view showing the typical rosette appearance with large utricles (arrows) surrounded by numerous smaller cells and monosporangia (arrowheads). **5.** Monosporangia (arrowhead) cut off singly from inner cortical cells. **6.** A further stage of monosporangia (arrowheads) cut off from inner cortical cells. Scale bars: Figs 2-3, 40 μm; Figs 4-6, 20 μm.

Reproductive morphology

Male gametophyte and tetrasporophytes were not seen. One to two pigmented, spherical monosporangia are cut off terminally from outer, stalk-like cortical cells (Figs 5, 6). Carpogonial branches arise on outer medullary filaments and are three-celled (Fig. 7): a terminal carpogonium with a projecting trichogyne, a hypogynous cell bearing two one-two celled sterile branches, and a basal cell bearing several sterile cells/filaments (Figs 8, 9). After presumed fertilization, the sterile branches on the hypogynous cell divide once, and the sterile filaments on the basal cell develop further to form a pericarp surrounding the carposporophyte (Figs 10-12). The fertilized carpogonium first cuts off a gonimoblast initial to one side (Fig. 13), then cuts off another gonimoblast initial to the other side (Fig. 14). Each gonimoblast initial divides rapidly into branched gonimoblast filaments (Fig. 15). The sterile branches on the hypogynous cell remain distinctive throughout early development of the carposporophyte (Fig. 15). The pit plugs between fer-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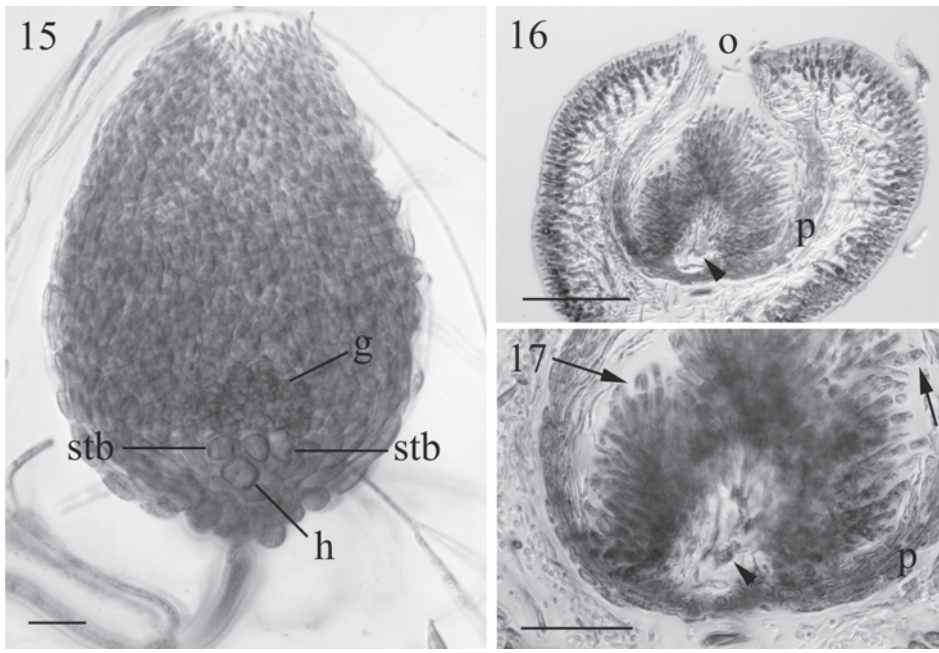

Figs 15-17. Reproductive structure of *Scinaia chinensis* (Tseng) Huisman. **15.** Young carposporophyte showing compact gonimoblast and the distinct sterile branches borne on the hypogynous cell. **16.** Cross-section of immature cystocarp showing pericarp with an ostiole and compact gonimoblast filaments with a central fusion cell (arrow). **17.** Cross-section of mature cystocarp showing the fusion cell (arrowhead) at basal part of carposporophyte and terminal carposporangia (arrows). Scale bars: Fig. 15, 40 μm; Fig. 16, 100 μm; Fig. 17, 50 μm. Abbreviation: g, gonimoblast; h, hypogynous cell; p, pericarp; stb, sterile branch.

tilized carpogonium, hypogynous cell, basal cell and inner gonimoblast cells break down to form a large fusion cell at the base of the carposporophyte at maturity (Figs 16, 17). Cystocarps are conical or pyriform in shape at maturity, 150-225 μm in diameter (Figs 15-17), ostiolate, with a well developed pericarp (Fig. 16). Carposporangia are ellipsoid to obovoid, borne in chains of two to three, and are 5-8 μm wide by 10-13 μm long (Figs 16-17).

Figs 7-14. Carpogonial branch formation of *Scinaia chinensis* (Tseng) Huisman. **7.** A young three-celled carpogonial branch just cut off from inner cortical cell. **8.** A fully developed carpogonial branch with the sterile initial borne on the hypogynous cell and sterile filaments. **9.** Mature carpogonial branch showing the second sterile initial borne on the hypogynous cell and sterile filaments. **10.** Cruciate arranged sterile branches on the hypogynous cell. **11.** Mature carpogonial branch with an enlarged hypogynous cell. **12.** Mature carpogonial branch with one one-celled sterile branch and one two-celled sterile branch. **13.** Early fertilization showing the gonimoblast initial cut off from carpogonium directly. **14.** A further stage of early fertilization showing the second gonimoblast initial issuing from the opposite side of fertilized carpogonium. Scale bar: Figs 7-14, 20 μm. Abbreviation: b, basal cell; cpg, carpogonium; gi1, gonimoblast initial 1; gi2, gonimoblast initial 2; h, hypogynous cell; p, pericarp; stb, sterile branch.

Table 2. A morphological comparison of relevant *Scinaia* species from the North Pacific Ocean.

Characters	*Plant height*	*Furcations*	*Width of segment*	*Length of segment*	*Thickness of cortex*	*Diameter of utricles*	*Diameter of cystocarp*	*Reference*
S. chinensis	Up to 3.5 cm	6-7 times	1-2 mm	4-6 mm	60-80 µm	14-20 µm	180-220 µm	Tseng, 1941
S. confusa	10-15 cm	10-15 times	2-3 mm	–	105-120 µm	–	280-300 µm	Setchell, 1914
S. okamurae	Up to 9 cm	10-11 times	1-1.5 mm	–	70-100 µm	–	120-135 µm	Setchell, 1914
S. undulata	6-7 cm	9-10 times	1.5-3 mm	–	83-90 µm	–	Young cystocarp	Setchell, 1914
S. chinensis	3-5 cm	6-7 times	1-1.5 mm	4-7 mm	70-90 µm	20-25 µm	150-225 µm	This study

–, data not shown.

DISCUSSION

Four species of *Scinaia*, *S. moniliformis* J. Agardh, *S. cottonii* Setchell (presently regarded as a synonym of *S. latifrons* Howe), *S. pseudojaponica* Yamada *et* Tanaka in Yamada, and *S. boergesenii* Tseng, have been recorded for Taiwan (Lewis & Norris, 1987). Anatomically, these species have cortices with abundant large colourless utricles and scarce small colourless cortical cells, the opposite of the cortical structure in our specimens in which there are numerous small colourless cortical cells and, only rarely, large colourless utricles. From a morphological point of view, our specimens seem to therefore have strong affinities with the genus *Gloiophloea,* which has numerous small pigmented cortical cells (Huisman, 1985). *Gloiophloea* is presently unknown in the North Pacific, the four species from the region previously attributed to the genus now included in *Scinaia*: *S. chinensis* (Tseng) Huisman, *S. confusa* (Setchell) Huisman, *S. okamurae* (Setchell) Huisman, and *S. undulata* (Montagne) Huisman. A comparison of these shows *Scinaia chinensis* can be distinguished from *S. okamurae* in its smaller plant size, fewer furcations, and larger cystocarp size, and can be distinguished with *S. confusa* and *S. undulata* in its smaller plant size, fewer furcations, narrower branch segment width and smaller cystocarp size (not known in *S. undulata*) (Table 2). Based on the above comparison (Table 2), our material apparently agrees in all morphological characters with *S. chinensis*. The main features of *Scinaia chinensis* are: 1) a very small thallus that never grows more than 5 cm in height; 2) fewer furcations, the axes never dividing more than seven times; 3) the presence of colourless utricle cells that do not differentiate until quite late in the development of the cortex; 4) one to two pigmented spherical monosporangia produced from outer, stalk-like cortical cells; 5) three-celled carpogonial branch with a carpogonium, a hypogynous cell and a basal cell; 6) only two one-two celled sterile branches borne on the hypogynous cell; 7) gonimoblast initials developed from the fertilized carpogonium; 8) a pericarp derived from the basal cell of the carpogonial branch; 9) a distinct fusion cell incorporated from the inner gonimoblast, the hypogynous cell and the basal cell; 10) carposporangia produced in chains of two to three.

The *Scinaia* assemblage, as conceived by Huisman (1985), is extensively distributed from tropical to cold-temperate region and consists of only two genera, *Gloiophloea* and *Scinaia*. After examining the vegetative and reproductive structures of the type specimens of four genera: *Scinaia forcellata* Bivona-Bernard, *Gloiophloea scinaioides* J. Agardh, *Pseudoscinaia snyderae* Setchell and *Pseudogloiophloea berggrenii* Levring, Huisman (1985) found that the cortical structures and the number of sterile branches on the hypogynous cell can be important diagnostic characters for distinguishing *Gloiophloea* and *Scinaia*. Utricle cells are completely lacking and there are three sterile branches borne on the hypogynous cell in *Gloiophloea*, whereas colorless utricles are present and there are only two sterile branches borne on the hypogynous cell in *Scinaia*.

Our studies show that *S. chinensis* is closely related to the genus *Scinaia* in having colourless utricles and only two sterile branches borne on a hypogynous cell, rather than related to *Gloiophloea*, which lacks colourless utricle cells and has three sterile branches cut off from the hypogynous cell. Based on the morphological congruence between *Scinaia chinensis* and the genus *Scinaia*, the combination of *Scinaia chinensis* (Tseng) Huisman is strongly supported.

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