



# New records of genus *Scenedesmus* (Chlorophyceae) found in Korea

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## Abstract

This study summarizes the taxonomic notes and distribution of 13 taxa of the genus *Scenedesmus* (Chlorophyceae) collected from several swamps, reservoirs, and rivers throughout South Korea from 2012 to 2014. In this study, light microscopy images of all 13 taxa are presented and briefly discussed with regard to their taxonomy, distribution, and ecology and environmental factors of occurrence sites. All 3 subgenera (subgenus *Scenedesmus* 1 taxon; subgenus *Acutodesmus* 2 taxa; subgenus *Desmodesmus* 10 taxa) are newly described in Korean freshwater algal flora: *S. linearis*, *S. acuminatus* var. *elongatus*, *S. acuminatus* var. *tetradesmoides*, *S. carinatus*, *S. denticulatus* var. *disciformis*, *S. gutwinskii* var. *heterospina*, *S. helveticus* f. *bicaudatus*, *S. lefevrei*, *S. oahuensis* var. *clathratus* f. *longiclathratus*, *S. oahuensis* var. *clathratus*, *S. panonicus*, *S. polydenticulatus*, and *S. tenuispina*.

**Key words:** Chlorophyceae, newly recorded species, *Scenedesmus*, South Korea

## INTRODUCTION

The family Scenedesmaceae is coccal green algae, which is arranged into microscopic, flat, spherical, and circular coenobia. This family is classified into 6 subfamilies and 28 genera (Komárek and Fott 1983). The subfamily Scenedesmoideae is composed of 8 genera. The genus *Scenedesmus*, which belongs to this subfamily, is the largest and taxonomically most difficult genus of coccal green algae. About 447 taxa of *Scenedesmus* has been recorded worldwide by Guiry and Guiry (2014) and 94 taxa have been recorded in Korea. Most of them were identified by traditional key characters such as cell shape and size, modes of cell arrangement in the coenobia, presence of spines and ridges on the cell wall and position of spines on the coenobia. But the morphological variability of its coenobia, cells, and cell wall sculptures has resulted in the description of many taxa and the present system is rather

complicated (Comas and Komárek 1984).

The morphological variabilities in *Scenedesmus* have been reported by some researchers after the 1960s (Trainor and Rowland 1968, Hegewald 1982, Comas and Komárek 1984, Hegewald and Silva 1988). The many structures of cell walls of *Scenedesmus* that are not visible under light microscopy are investigated using electron microscope. Hegewald and Silva (1988) reported that these electronic microscopical criteria have been used taxonomically by Komárek and Ludvik (1971), and Hindák (1990).

The genus *Scenedesmus* species have been identified and classified to the ultrastructure by an electron microscope, but this study is based on morphological characteristics of Chlorococcales (Scenedesmaceae) as seen under the light microscope. The samples for this study were collected at lakes, ponds, swamps and rivers throughout

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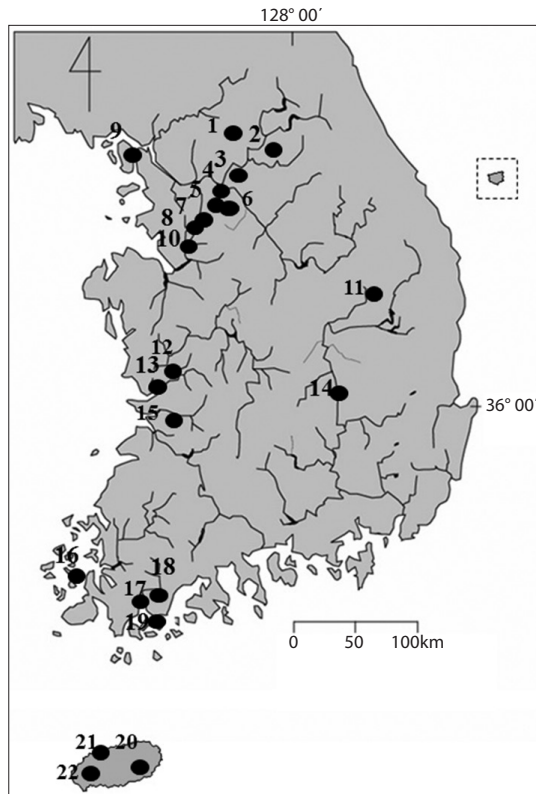
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**Fig. 1.** Showing the sampling sites of the genus *Scenedesmus* in South Korea.

Korea and briefly discussed with regard to their taxonomy, distribution, and ecology in South Korea (Fig. 1 and Table 1).

**MATERIALS AND METHODS**

The samples of the genus *Scenedesmus* (Chlorophyceae, Chlorococcales) were collected at 112 sites including ponds, swamp, reservoirs, lakes and rivers from 2012 to 2014. Sampling sites were located throughout the country. All samples were collected using 10 µm or 20 µm mesh-sized plankton nets with vertical and/or horizontal towing, or submerged benthic or soil algae with spoid or brush. The samples were immediately fixed with Lugol’s iodine solution (0.5%) to immobilize the cells and facilitate microscopic examination. To examine the fine structures and cellular shapes, and to identify and classify the chlorococcal species, temporary slides were made using the following steps: 1) the phytoplankton samples (chlorococcal algae) were mixed with glycerin in micro tubes, and 2) the mixed samples were placed by drop on slide glass, and fixed in position with cover slides. Permanent

slides were made using the following steps: 1) the phytoplankton samples (chlorococcal algae) were mixed with liquid glycerol gelatin to mount on histochemical slides (Sigma-®); 2) the mixed samples were placed drop-wise on slide glass and fixed in position with a cover slide; and 3) samples were affixed at the margin of a cover glass with manicure (Thecashop-®). The temporary and permanent slides were observed at x200-x1,000 magnification using light microscope (LM) (Axioskop 20 and Axio Imager A2; Carl Zeiss, Oberkochen, Germany) while an attached digital camera (Zeiss AxioCam HRC; Carl Zeiss, Jena, Germany) was used to capture images. The scale bar in illustrations represents 10 µm.

At each site, physical and chemical factors of water were recorded during the sampling period (Table 1). Water temp. (Water temperature, °C) and EC (electric conductivity) was measured in situ using a portable thermometer and EC meter (Orion 5-star; Thermo Fisher Scientific, Waltham, MA, USA), and pH was measured in situ using a pH meter (Ultrabasic-5; Denver Instrument, Bohemia, NY, USA) respectively. The data for total nitrogen (TN) and total phosphate (TP) concentrations at each sampling site was referred from the water information system of the Ministry of Environment (NIER 2014).

The genus *Scenedesmus* (Chlorophyceae, Chlorococcales) was identified mainly based on Prescott (1962), Uherkovich (1966), Hirose et al. (1977), Hegewald and Schnepf (1979) Komárek and Fott (1983), Yamagishi and Akiyama (1984-1997), Hegewald and Silva (1988), and John and Tsarenko (2002).

**RESULTS AND DISCUSSION**

**Order Chlorococcales A. Pascher  
Family Scenedesmaceae Oltmanns  
Genus *Scenedesmus* Meyen  
Subgenus *Scenedesmus* Hegewald**

***Scenedesmus linearis* Komárek (Figs. 2A-2E)**

**References:** Komárek and Fott 1983, p 832, taf. 226, fig. 6; Hegewald and Silva 1988. p 298, fig. 487.

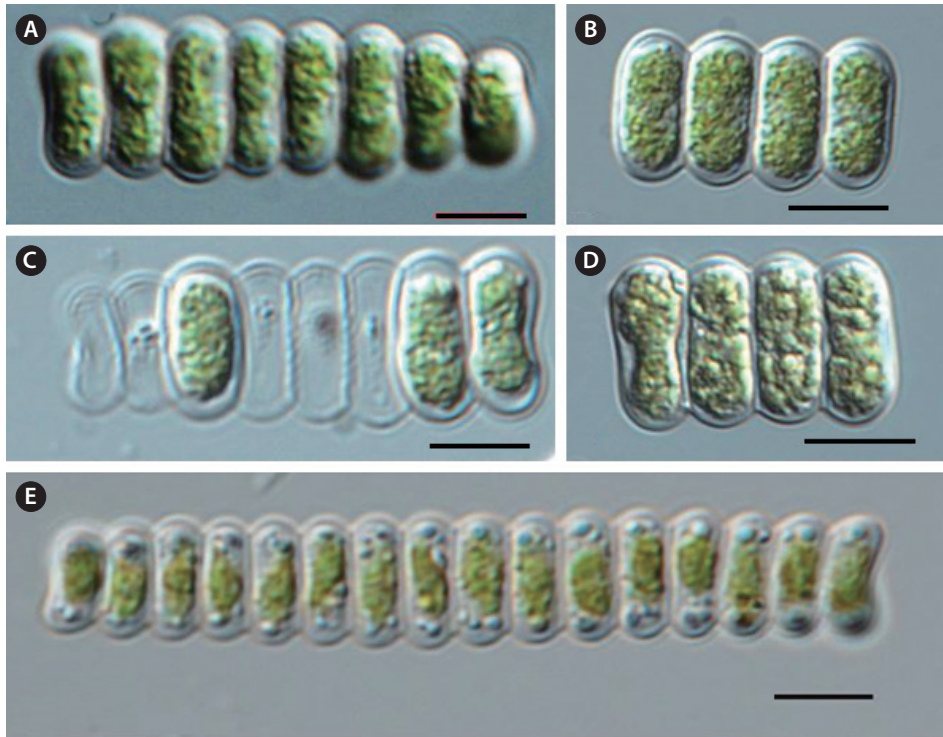
**Description:** Coenobia are 4-8-16 cells, linearly arranged cells, with 3-quarters of the cell length conjoined. cells are cylindrical with broadly rounded cell poles and slightly thick cell walls. The outsides of the marginal cells are slightly concave. Cell walls are smooth without teeth, spines, or granulates. Cells have a single chloroplast and a pyrenoid. Cells are 14-20 µm long and 5-8 µm wide.

**Occurrence sites:** 3, 14, 18, 20, 21, 22 (Table 1 and Fig. 1)

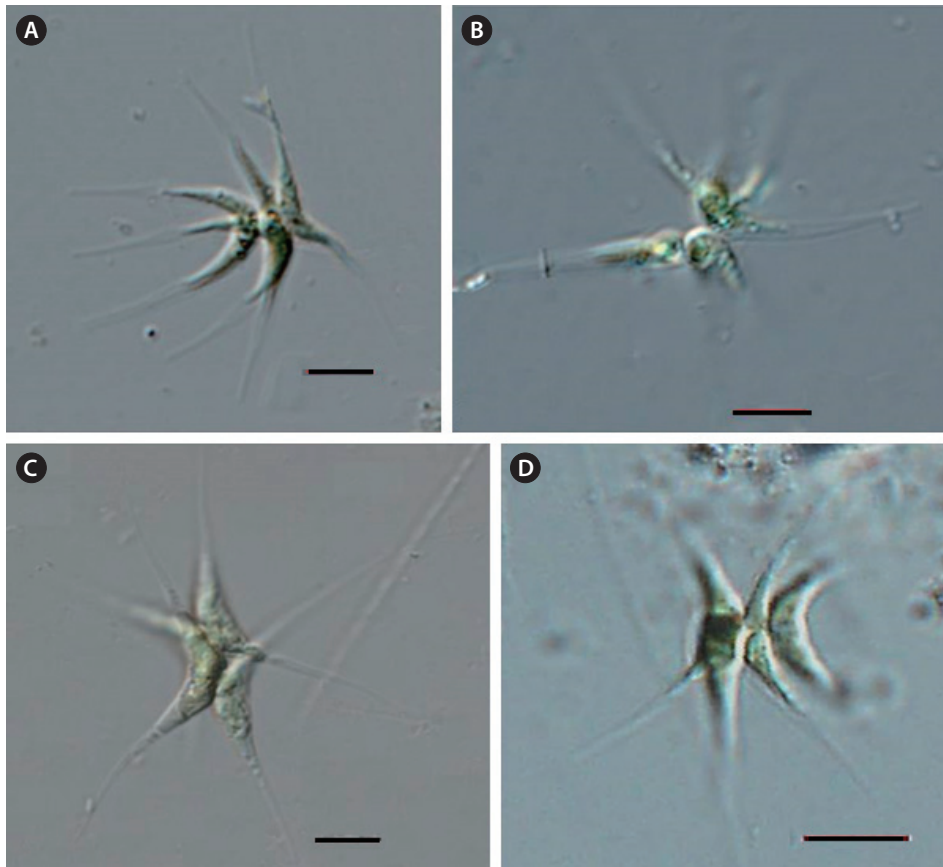
**Table 1.** Information of sampling sites of the genus *Scenedesmus* in South Korea

Site no. / sampling site	Sampling dates	Locality	Environmental factors
1. Ugeum fish pond	21 Jun 2012, 06 May 2013	Gasam, Gasan, Pocheon, Gyeonggi-do	Water temp. 26.6-28.2°C, pH 7.5-7.9, EC 123-218 $\mu\text{S cm}^{-1}$ , TN 1.686 $\text{mg L}^{-1}$ , TP 0.010 $\text{mg L}^{-1}$
2. Pond at Elysian resort	18 Jul 2013, 15 Jul 2014	Baekyang, Chuncheon, Gangwon-do	Water temp. 27.5-30.0°C, EC 144-272 $\mu\text{S cm}^{-1}$
3. Bukhan River	26 Aug 2012	Yangsuri, Yangpyeong, Gyeonggi-do	Water temp. 30.2°C, EC 238 $\mu\text{S cm}^{-1}$
4. Lake 88, Olympic Park	07 Sep 2012, 19 Jul 2013	Bangyi, Songpa, Seoul	Water temp. 29.8°C, EC 193-527 $\mu\text{S cm}^{-1}$
5. Naksaeang Reservoir	24 Apr 2013	Gumi, Bundang, Seongnam, Gyeonggi-do	Water temp. 20.9°C, pH 6.1, EC 214.4 $\mu\text{S cm}^{-1}$
6. Pond at Jungang Park	20 Sep 2013	Sunae, Bundang, Seongnam, Gyeonggi-do	Water temp. 26.3°C, pH 8.2, EC 320-407 $\mu\text{S cm}^{-1}$
7. Lake Seohe	12 Apr 2013, 24 Apr 2013	Hwaseo, Suwon, Gyeonggi-do	Water temp. 20.9-30.4°C, pH 6.5-7.3, EC 434-580 $\mu\text{S cm}^{-1}$ , TN 5.965-6.278 $\text{mg L}^{-1}$ , TP 0.121-0.164 $\text{mg L}^{-1}$
8. Wangsong Reservoir	27 May 2012	Bugok, Uiwang, Gyeonggi-do	Water temp. 29.5°C, pH 7.8, EC 435 $\mu\text{S cm}^{-1}$ , TN 3.606 $\text{mg L}^{-1}$ , TP 0.107 $\text{mg L}^{-1}$
9. Gilsang Reservoir	29 May 2012	Gilsang, Ganghwa, Incheon	Water temp. 25.0°C, pH 6.2, EC 159 $\mu\text{S cm}^{-1}$
10. Banweol Reservoir	24 Apr 2013	Dundae, Gumpo, Gyeonggi-do	Water temp. 19.1°C, pH 6.3, EC 267 $\mu\text{S cm}^{-1}$ , TN 2.216 $\text{mg L}^{-1}$ , TP 0.047 $\text{mg L}^{-1}$
11. Jungdeok Reservoir	05 Jun 2013	Jungdeok, Sangju, Gyeongsangbuk-do	Water temp. 31.1°C, pH 6.0, EC 223 $\mu\text{S cm}^{-1}$ , TN 0.606-0.773 $\text{mg L}^{-1}$ , TP 0.055-0.182 $\text{mg L}^{-1}$
12. Chukdong Reservoir	22 Mar 2013, 12 Aug 2013	Chukdong, Hansan, Seocheon, Chungcheongnam-do	Water temp. 17.9-33.2°C, EC 130 <sup>36</sup> $\mu\text{S cm}^{-1}$ , TN 0.751-0.848 $\text{mg L}^{-1}$ , TP 0.052-0.060 $\text{mg L}^{-1}$
13. Estuary dam lake of Geumgang River	22 Mar 2013	Dosam, Maseo, Seocheon, Chungcheongnam-do	Water temp. 14.4°C, pH 6.2, EC 263 $\mu\text{S cm}^{-1}$ , TN 3.326 $\text{mg L}^{-1}$ , TP 0.027 $\text{mg L}^{-1}$
14. Gumi-bo, Nakdong River	09 Sep 2013	Won-ri, Seosan, Gumi, Gyeongsangbuk-do	Water temp. 31.8°C, pH 8.2, EC 159 $\mu\text{S cm}^{-1}$ , TN 1.389 $\text{mg L}^{-1}$ , TP 0.041 $\text{mg L}^{-1}$
15. Namyang Reservoir	21 Jul 2013	Namsan, Hwagsan, Gimje, Jeollabuk-do	Water temp. 26.9°C, EC 202 $\mu\text{S cm}^{-1}$
16. Pond at Deoksan	24 Jul 2013	Deoksan, Bigeum, Sinan, Jeollanam-do	Water temp. 27.9-28.9°C, EC 175-243 $\mu\text{S cm}^{-1}$
17. Namchang Reservoir	29 May 2014	Namchang, Bukpyeong, Haenam, Jeollanam-do	Water temp. 27.1°C, EC 104 $\mu\text{S cm}^{-1}$
18. Imcheon Reservoir	29 May 2014	Imcheon, Gangjin, Jeollanam-do	Water temp. 29.5°C, pH 6.7, EC 155 $\mu\text{S cm}^{-1}$ , TN 0.591-0.959 $\text{mg L}^{-1}$ , TP 0.021-0.043 $\text{mg L}^{-1}$
19. Daeweeolje	29 May 2014	Yongweol, Sinjeon, Gangjin, Jeollanam-do	Water temp. 30.5°C, pH 6.6, EC 117 $\mu\text{S cm}^{-1}$ , TN 1.420 $\text{mg L}^{-1}$ , TP 0.048 $\text{mg L}^{-1}$
20. Bongumott	31 May 2014	Boseong, Daejeong, Seoguiipo, Jeju	Water temp. 30.4°C, pH 6.3, EC 251 $\mu\text{S cm}^{-1}$
21. Dombaemul	06 Apr 2013	Yeoyeom, Aewol, Jeju	Water temp. 20.2°C, pH 6.6, EC 236 $\mu\text{S cm}^{-1}$
22. Bilemott	31 May 2014	Jeoji, Hangyeong, Jeju	Water temp. 25.8°C, pH 6.6, EC 86.4 $\mu\text{S cm}^{-1}$

Temp, temperature; EC, electric conductivity; TN, total nitrogen; TP, total phosphate.



**Fig. 2.** *Scenedesmus linearis*. Scale bars, 10  $\mu$ m.



**Fig. 3.** *Scenedesmus acuminatus* f. *elongatus*. Scale bars, 10  $\mu$ m.



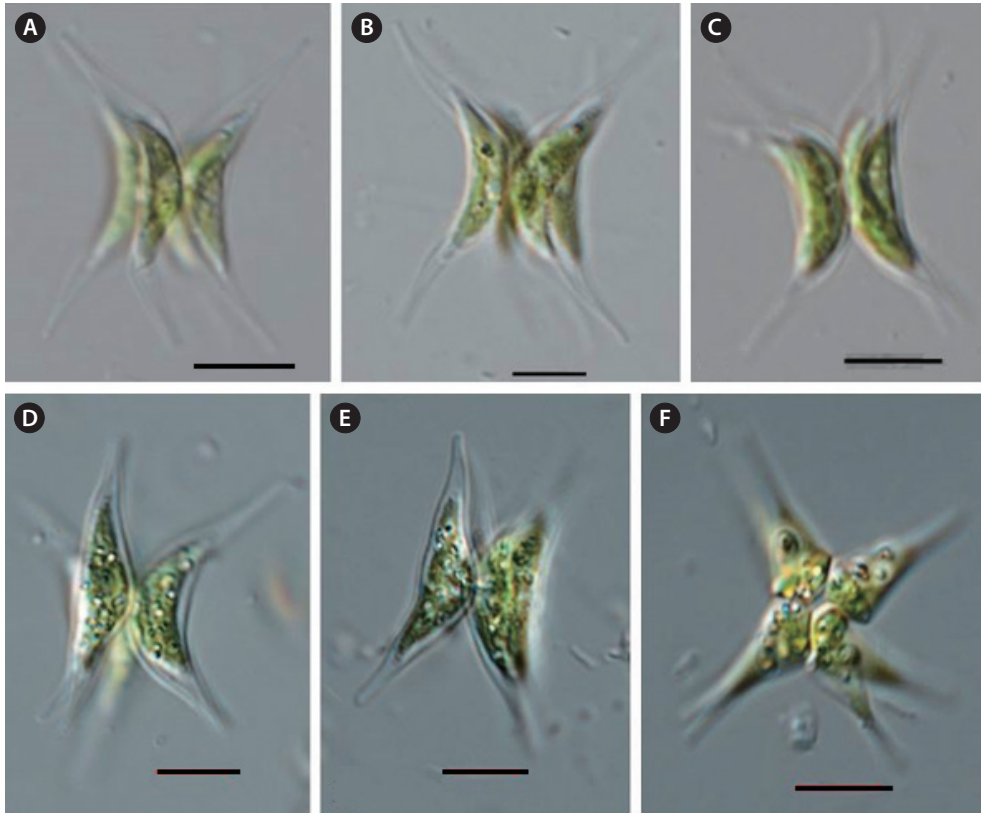


Fig. 4. *Scenedesmus acuminatus* f. *tetradesmoides*. Scale bars, 10  $\mu$ m.

### Subgenus *Acutodesmus* Hegewald

#### *Scenedesmus acuminatus* var. *elongatus* G.M. Smith

(Figs. 3A-3D)

**References:** Uherkovich 1966, p 43, taf. III, Abb. 80; Komárek and Fott 1983, p 844, taf. 229, fig. 2; Hegewald and Silva 1988, p 52, fig. 65.

**Description:** Coenobia are composed of 4-8 cells, commonly 4 cells, always forming a curved plate, with irregular twists. Cells are longer than *S. acuminatus* and proportionally narrower, and cells narrow and become fusiform, tapered, or pointed at the pole, while the outside is concave. The cell wall is smooth, without teeth, spines, or granulates. Cells have a single chloroplast and a pyrenoid. Cells are 50-60  $\mu$ m long and 3-6  $\mu$ m wide.

**Occurrence site:** 4 (Table 1 and Fig. 1)

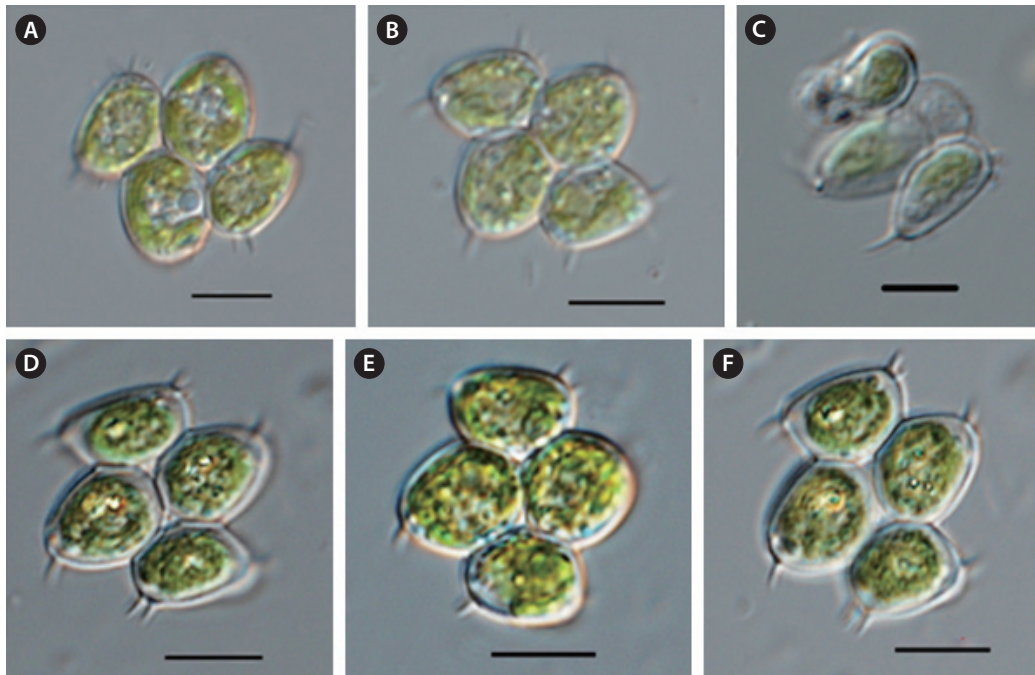
**Remarks:** Komárek and Fott (1983) and Hegewald and Silva (1988) included this taxon into *S. acuminatus*. However, Komárek and Fott (1983) suggested that the figures related to *S. acuminatus* var. *elongates* are longer and more slender than *S. acuminatus*, and has slightly different morphological characteristics from *S. acuminatus*. Some figures of *S. acuminatus* var. *tetradesmoides* are

similar to *S. acuminatus* var. *elongatus*, but it is shorter, wider, and less pointed than *S. acuminatus* var. *elongatus*. Some figures showed similarities to *S. acuminatus* var. *tetradesmoides* of Smith (1916). Hegewald (1979) collected the samples at the Haber River, Torfvanns and Dülmen. The cellular arrangements and morphological characteristics of the samples showed a striking difference from *S. acuminatus*. However, he included this taxon into *S. acuminatus* as a synonym. Many workers got confused about the morphological characteristics of cells and coenobia. This taxon is not merged into *S. acuminatus*, but separated into 4 taxa (*S. acuminatus*, *S. acuminatus* f. *tortuosus*, *S. acuminatus* var. *elongates*, *S. acuminatus* var. *tetradesmoides*) in this study, but further study is required to determine if it can be merged as a synonym or needs to be separated as an independent taxon.

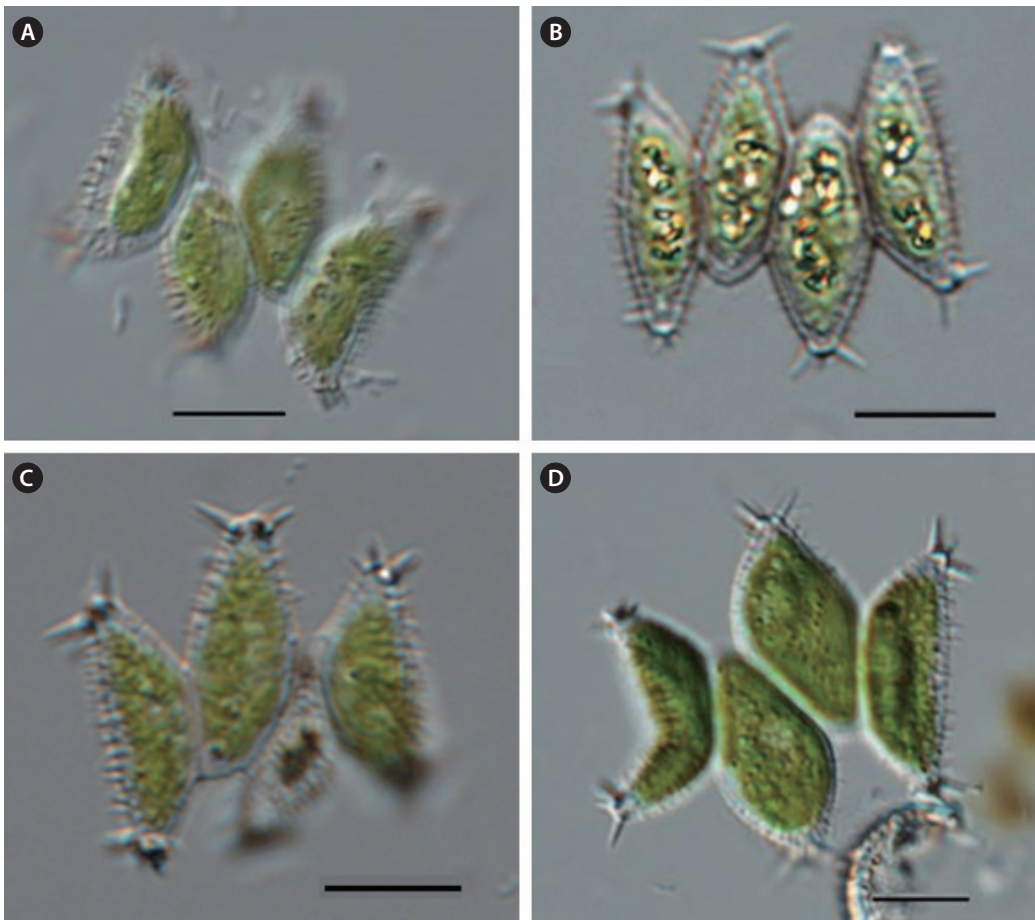
#### *Scenedesmus acuminatus* var. *tetradesmoides* G.M. Smith (Figs. 4A-4F)

**References:** Komárek and Fott 1983, p 842, taf. 228, fig. 5; Hegewald and Silva 1988, p 55, fig. 70.

**Description:** Coenobia are composed of 4-8 cells, commonly 4 cells, always forming a curved plate. Cells are ar-



**Fig. 5.** *Scenedesmus denticulatus* var. *disciformis*. Scale bars, 10  $\mu$ m.



**Fig. 6.** *Scenedesmus polydenticulatus*. Scale bars, 10  $\mu$ m.

cuate or long crescent shaped, and adjoined side by side along a parallel axis, and radially arranged in apical view. Cells narrow and become fusiform, tapered, or pointed at the poles, and the outside is concave. The cell wall is smooth, without teeth, spines, or granulates. Cells have a single chloroplast, with a pyrenoid. Cells are 25-30 µm long and 5-8 µm wide.

**Occurrence sites:** 4, 14 (Table 1 and Fig. 1).

**Remarks:** Korshikov (1953) included this taxon into the basionym of *S. acuminatus* f. *tetradesmoides*. However, Komárek and Fott (1983) included *S. acuminatus* f. *tetradesmoides* and *S. tetradesmiformis* into this taxon as a synonym. The figure of this taxon in Komárek and Fott (1983) is slightly longer than the original figure in Smith (1916), and is narrower and longer than *S. acuminatus*. This taxon is identified and classified according to Komárek and Fott (1983).

### Subgenus *Desmodesmus* Chodat

#### *Scenedesmus denticulatus* var. *disciformis* Hortobagyi (Figs. 5A-5F)

**References:** Hegewald and Silva 1988, p 200, fig. 315; John and Tsarenko 2002, p 392, pl. 95, fig. I.

**Description:** Coenobia are composed of 4-8 cells, mostly arranged linearly, or with alternating cells in 1 or 2 rows, tightly joined without any space between the cells. Cells are broadly ovoid with 2-3 short teeth, sometimes outwardly directed and confined to the outer pole at inner cells and to both poles at the marginal cells, with or without fine granulates on the cell wall. Cells have a single chloroplast and a pyrenoid. Cells are 10-15 µm long and 7-10 µm wide.

**Occurrence sites:** 4, 9, 12, 16, 19 (Table 1 and Fig. 1).

**Remarks:** Komárek and Fott (1983) included the species having characteristics of *S. denticulatus* var. *disciformis* and *S. denticulatus* var. *fenestratus* into *S. denticulatus* as a synonym. But John and Tsarenko (2002) identified it as the mutant of *S. denticulatus*. The cells in this research were of wider widths, more egg-shaped, and had shorter protuberance at the end than Komárek and Fott (1983).

#### *Scenedesmus polydenticulatus* Hortobagyi (Figs. 6A-6D)

**References:** Komárek and Fott 1983, p 868, taf. 234, fig. 10; Hegewald and Silva 1988, p 398, fig. 643; Yamagishi and Akiyama 1995, p 15, pl. 73, figs. 1-6.

**Description:** Coenobia are composed of 2-4-8 cells, mostly arranged linearly or in 1 or 2 rows of alternating cells that are rarely solitary, and tightly joined with or without a space between cells. Cells are broadly ovoid

with 1-3-4 outwardly directed short teeth, and are confined to the outer pole at inner cells and to both poles at the marginal cells, with fine spines on the cell wall. Cells have a single chloroplast, with a pyrenoid. Cells are 15-25 µm long and 10-15 µm wide.

**Occurrence sites:** 7, 2, 19, 21 (Table 1 and Fig. 1).

**Remarks:** Komárek and Fott (1983) included *S. denticulatus* var. *polyspinosus* into *S. smithii* as a synonym. Taf. 234, fig. 4 in Komárek and Fott (1983) is referred to as the original figure of Biswas (1934), and taf. 234, fig. 10 is referred to as the original figure of *S. polydenticulatus*. These figures show different characteristics of *S. spinulatus*. Hegewald and Silva (1988) agreed with Komárek and Fott (1983), who included them as a synonym. And Hegewald and Silva (1988) merged *S. polydenticulatus*, *S. denticulatus* var. *polyspinosus*, *S. smithii* var. *indicus*, *S. smithii* var. *linaeris* and *S. smithii* var. *polyspinosus* into *S. polydenticulatus* as a synonym. *S. smithii* var. *indicus* and *S. smithii* var. *linaeris* do not have short spines or granulates on the cell wall, but *S. smithii* var. *polyspinosus* and *S. denticulatus* var. *polyspinosus* have short spines or granulates distributed on the cell wall and they are similar to *S. spinulatus*. This taxon is identified and classified as *S. polydenticulatus* on the basis of the distributed short spines on the cell wall in this study.

#### *Scenedesmus lefevrei* Deflandre (Figs. 7A-7E)

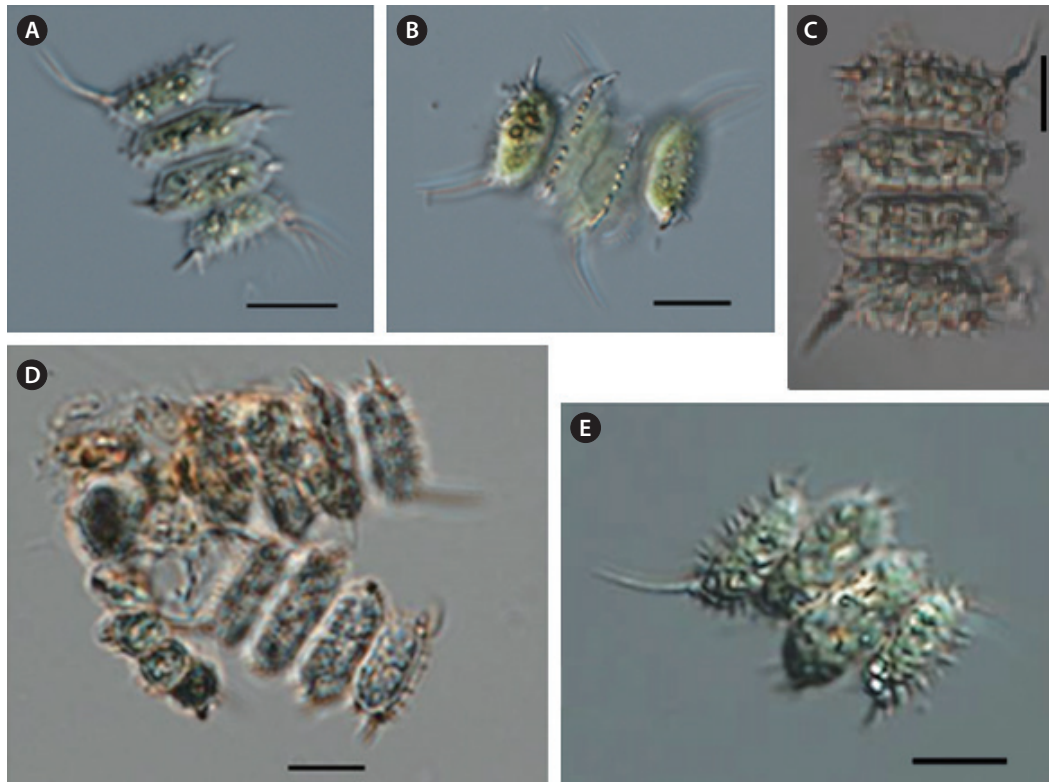
**References:** Komárek and Fott 1983, p 874, taf. 236, fig. 4; Hegewald and Silva 1988, p 295, fig. 481.

**Description:** Coenobia are composed of 2-(4)-8 cells, linearly arranged in 1 row, with contact up to three-quarters of the cell length. Cells vary in shape from ellipsoidal to cylindrical, and are sometimes slightly asymmetrical, rounded, or tapered at the poles. The cells have short spines at the poles of the inner cells, while the marginal cells have slightly curved spines at the pole of the outer cells with a single longitudinal row of warty teeth or rib-like structure on the side of each cell. Cells have a single chloroplast, with a pyrenoid. Cells are 15-25 µm long and 7-12 µm wide.

**Occurrence sites:** 1, 7 (Table 1 and Fig. 1).

**Remarks:** Deducenko-Scegoleva (1949) included *S. lefevrei* into the basionym of *S. quadricauda* var. *lefevrei*. Komárek and Fott (1983) included *S. maculosus*, *S. quadricauda* var. *spinousus*, *S. decorus* var. *bicaudatus*, *S. lefevrei* var. *maguinii* and *S. lefevrei* var. *semiserratus* f. *bicaudatus* into *S. lefevrei* as a synonym. However, Coenobia of *S. maculosus* and *S. quadricauda* var. *spinousus* are composed of 4 cells, with 2 long spines at the poles of their marginal cells. It is distributed along a longitudinal ridge





**Fig. 7.** *Scenedesmus lefevrei*. Scale bars, 10  $\mu\text{m}$ .

structure. Considering the differences in characteristics of *S. maculosus* and *S. quadricauda* var. *spinosus*, these taxa are not merged into the synonym of *S. lefevrei* in this study.

Kiriakov (1977) reported *S. lefevrei* var. *semiserratus* f. *bicaudatus*, the basionym of which was *S. lefevrei* var. *magninii*. *S. lefevrei* var. *semiserratus* f. *bicaudatus* needs to be included into *S. lefevrei* as synonym, because the characteristics of this taxon are similar to *S. lefevrei*. Taf. X, abb. 424-427 in Uherkovich (1966) and the original figures of Deflandre (1924) showed different characteristics of long spines at the poles of the marginal cells. The original figure showed a long spine at one end and a short spine at the other end, with longitudinally distributed small spines on the cell walls at both sides. Uherkovich (1966) described the cells of this taxon as having the same length of long spines at the pole of outside cells, with longitudinal small spines on the inner cell wall, while there were no small spines on the sides of cell wall. It is possible to confuse the identification of this taxon on the basis of the two figures.

***Scenedesmus pannonicus* Hortobagyi (Figs. 8A-8C)**

**References:** Komárek and Fott 1983, p 882, taf. 238, fig.

6; Hegewald and Silva 1988, p 369, fig. 598; John and Tsarenko 2002, p 397, pl. 95, fig. O.

**Description:** Coenobia are composed of 4-8 cells, rarely 2 cells, arranged linearly or in slightly alternating cells. Cells are ellipsoid, cylindrical, or ovoid, with sides joined in linear series. The marginal cells have a short stout spine at the poles, while the inner cells have a stout spine at one pole or both poles. Cell walls are smooth. Cells have a single chloroplast, with a pyrenoid. Cells are 10-25  $\mu\text{m}$  long and 6-12  $\mu\text{m}$  wide.

**Occurrence sites:** 1, 4, 5 (Table 1 and Fig. 1).

**Remarks:** Komárek and Fott (1983) included *S. naegelii*, *S. pannonicus* f. *heterocaudatus*, *S. longus*, and *S. intermedius* var. *balatonicus* f. *halophilus* into *S. pannonicus* as synonyms. Among these taxa, *S. pannonicus* f. *heterocaudatus* is found to be similar to *S. pannonicus*, but other taxa differed from the original figures (Hegewald and Silva 1988). Therefore, one needs to double check before merging these taxa into a synonym. Hegewald et al. (1988) collected the samples from Madurai, India, and found some differences from the original sample. Coenobia are composed of 4-8 cells, with distributed longitudinal granulates or ridge structures on the cell wall. It encloses



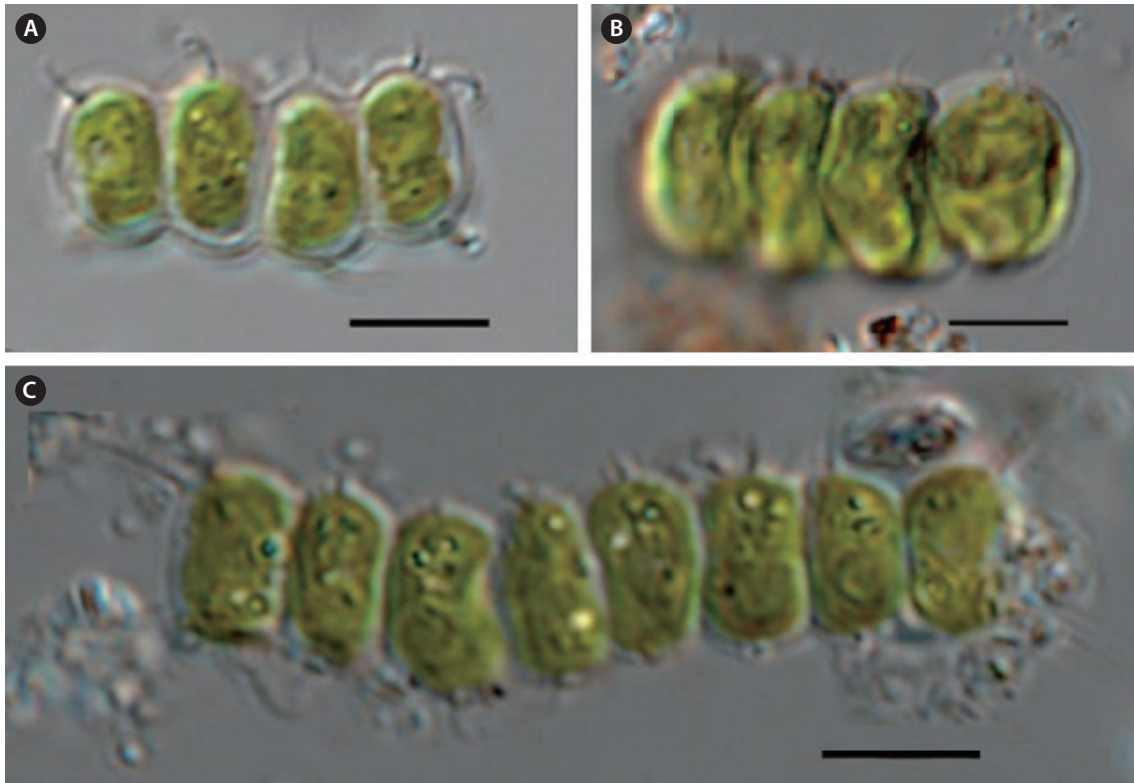


Fig. 8. *Scenedesmus pannonicus*. Scale bars, 10  $\mu$ m.

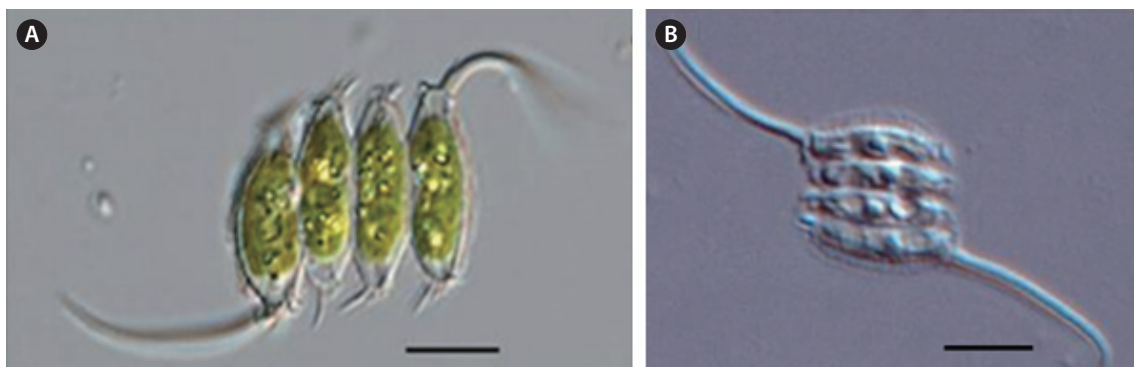


Fig. 9. *Scenedesmus helveticus* f. *bicaudatus*. Scale bars, 10  $\mu$ m.

coenobia with gelatinous material. However, the identified taxon from this study has a similar cell structure to Hegewald et al. (1988), but differed from the ridge structure on the cell wall.

***Scenedesmus helveticus* f. *bicaudatus* Korsikov (Figs. 9A-9B)**

**References:** Hegewald and Silva 1988, p 260, fig. 418.

**Description:** Coenobia are composed of 2-4-8 cells, mostly arranged in a linear series or a slightly alternating

manner. Cells are spindle, or elliptical shaped, and are tapered to conically rounded poles. The inner cells are with or without small teeth, and the marginal cells have elongated ends, with a straight or slightly curved long spine at one pole. The outer wall of marginal cells is straight or slightly convex, with wing-like structures on the side of the marginal cell. The cell wall is smooth, with continuous or interrupted longitudinal ribs. Cells have a single chloroplast, with a pyrenoid. Cells are 15-25  $\mu$ m long and

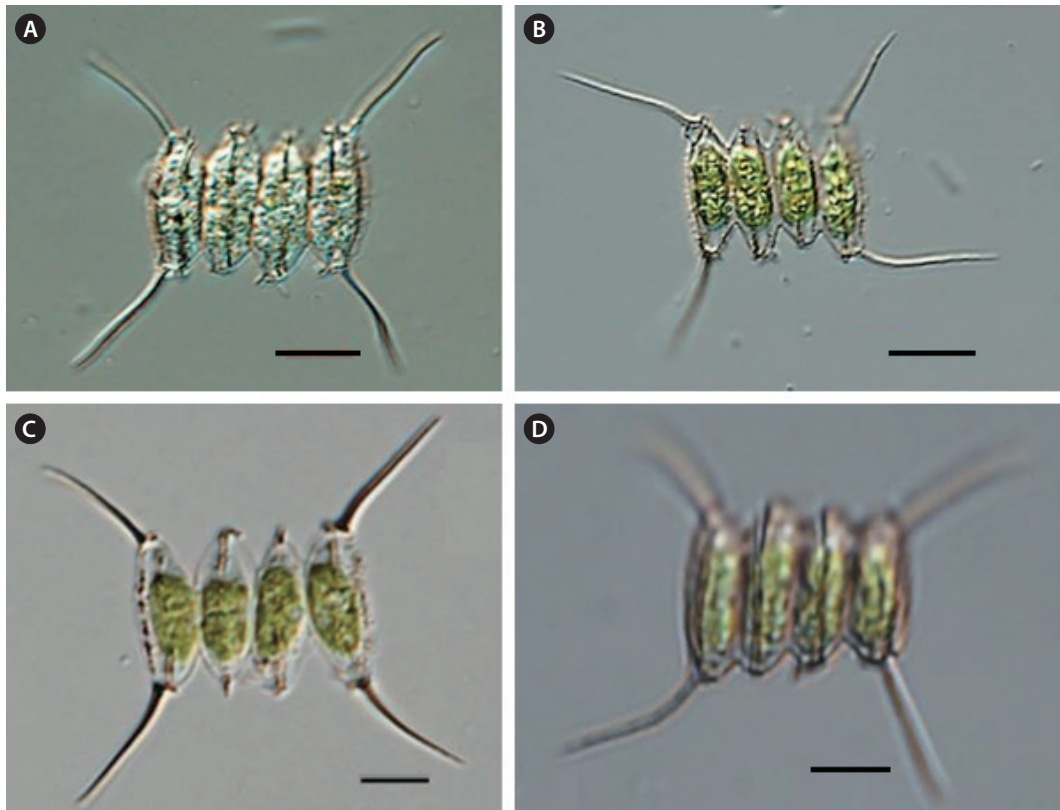


Fig. 10. *Scenedesmus carinatus*. Scale bars, 10  $\mu$ m.

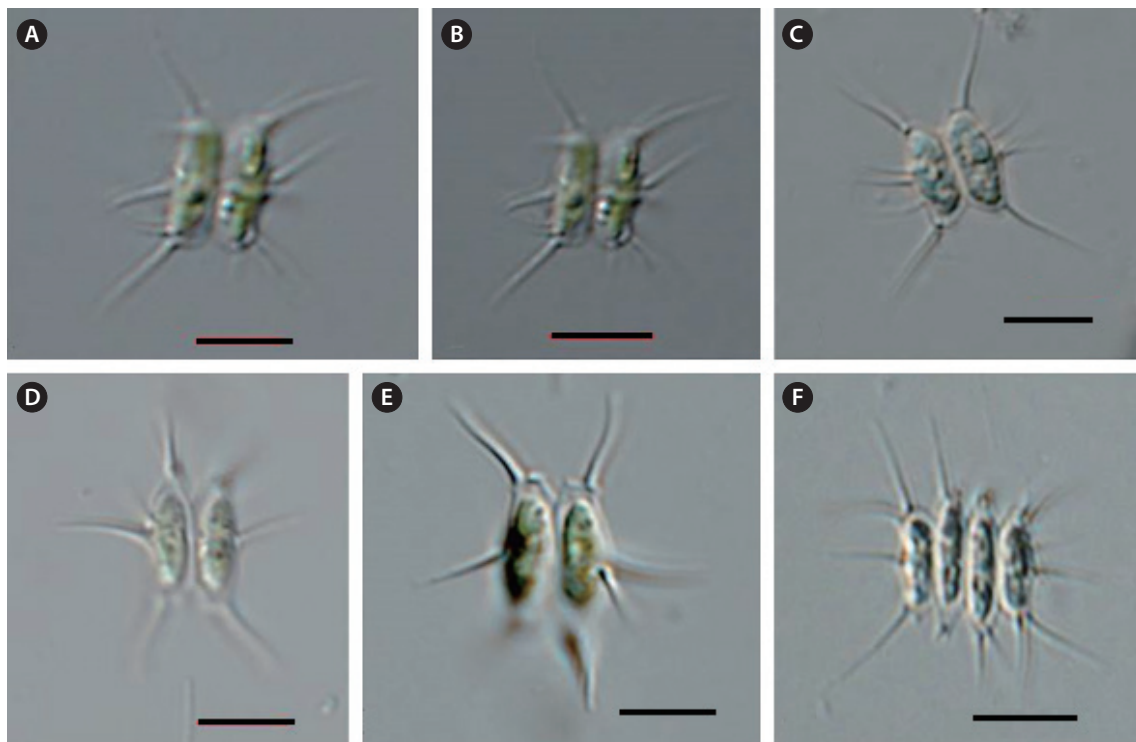


Fig. 11. *Scenedesmus tenuispina*. Scale bars, 10  $\mu$ m.

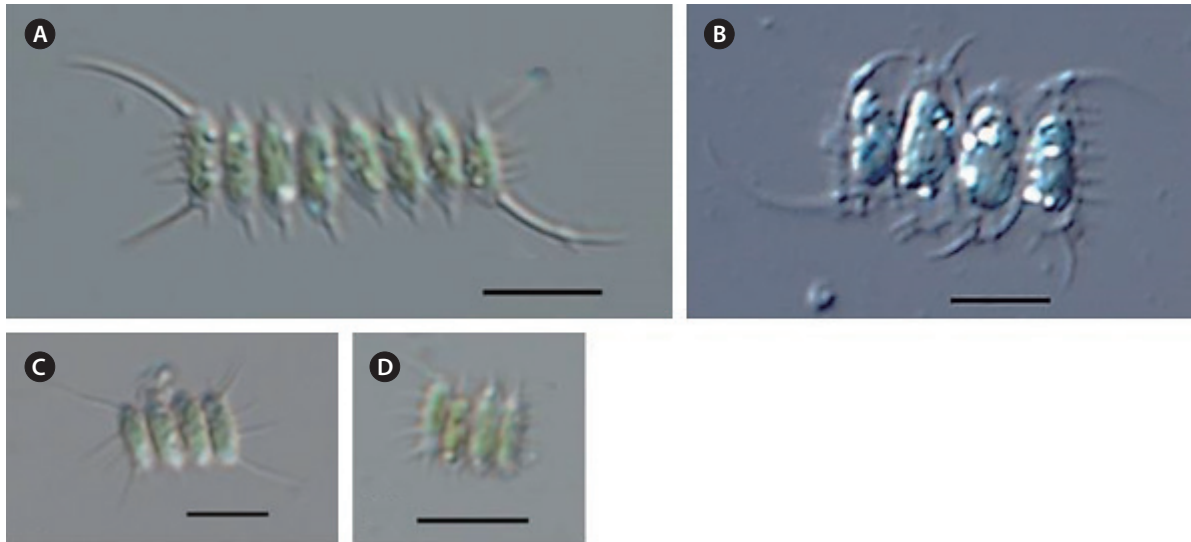


Fig. 12. *Scenedesmus gutwinskii* var. *heterospina*. Scale bars, 10  $\mu$ m.

5-8  $\mu$ m wide.

**Occurrence sites:** 11, 15, 17 (Table 1 and Fig. 1).

***Scenedesmus carinatus* (Lemmermann) Chodat (Figs. 10A-10D)**

**References:** Komárek and Fott 1983, p 913, taf. 246, fig. 3; Hegewald and Silva 1988, p 141, fig. 569.

**Description:** Coenobia are composed of (2)-4-8 cells, arranged in a linear series or slightly alternating row along the sides. Cells are long-fusiform, ellipsoidal, or navicula-shaped, with a conical or beaked pole. Cells have forked teeth spines on the poles and distinct longitudinal ribs. The marginal cells have long curved spines at the poles, and the outer side wall of marginal cells are straight or slightly convex. Cells have a single chloroplast, with a pyrenoid. Cells are 20-30  $\mu$ m long and 4-8  $\mu$ m wide.

**Occurrence sites:** 2, 4, 6, 7, 9, 17 (Table 1 and Fig. 1).

**Remarks:** Lemmermann (1899) reported the new species *S. opoliensis* var. *carinatus*. Chodat (1913) reported *S. carinatus* on the basis of a basionym *S. opoliensis* var. *carinatus*. Komárek and Fott (1983) described *S. opoliensis* var. *carinatus* again, and included *S. carinatus* var. *hanoinensis*, *S. armatus* (var. *bolgariensis*) f. *crassicaudatus*, and *S. armatus* (var. *bolgariensis*) f. *bicaudato-granulatus* into this taxon as synonyms. The former two taxa are similar to *S. carinatus*, but the latter taxon is different from *S. carinatus*.

***Scenedesmus tenuispina* Chodat (Figs. 11A-11F)**

**References:** Komárek and Fott 1983, p 916, taf. 247, fig.

1; Hegewald and Silva 1988, p 526, fig. 852.

**Description:** Coenobia are composed of 2-4(-8) cells, arranged in a linear series or slightly alternating row along the sides. Cells are long-ovoid and ellipsoidal with pointed poles. One to two spines are on the poles of the inner cells. The marginal cells have 1-3 spines of equal cell length at the poles. The outside wall of marginal cells is straight or slightly convex, with 2-5 spines on the opposite side. Cells have a single chloroplast, with a pyrenoid. Cells are 10-15  $\mu$ m long and 3-7  $\mu$ m wide.

**Occurrence sites:** 1, 4, 6, 8, 12, 13 (Table 1 and Fig. 1).

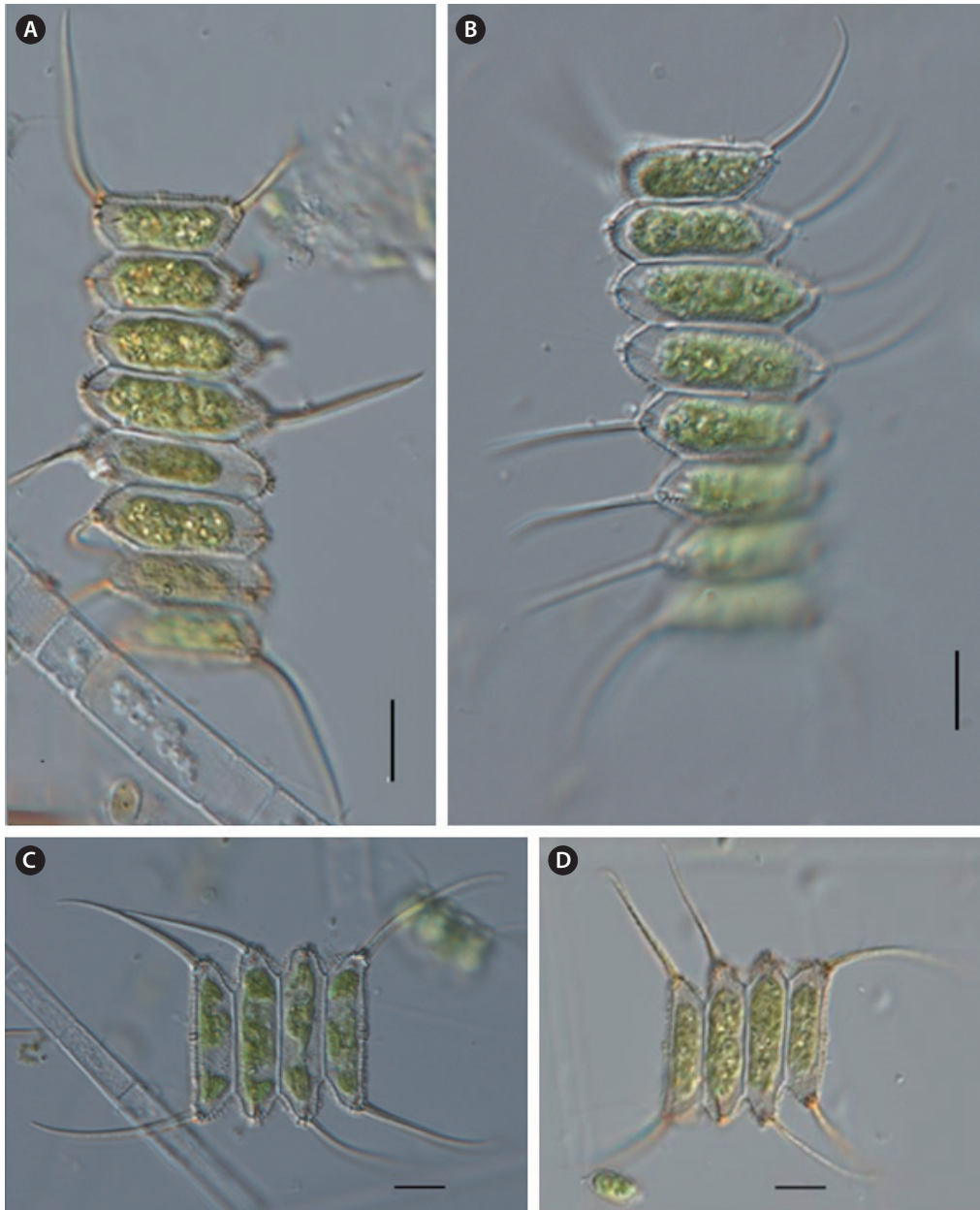
**Remarks:** Uherkovich (1966) reported new species *S. spinosus* var. *tenuispina* on the basis of the basionym *S. tenuispina*. However, this new variety was invalid because there was no sufficient reference to basionym (Hegewald and Silva 1988). It was classified with *S. tenuispina*, not *S. spinosus* var. *tenuispina* according to Uherkovich (1966). This taxon has not been reported in Korea, because Uherkovich (1966) included *S. tenuispina* into *S. spinosus*, and Korean researchers have identified *S. spinosus* on the basis of Uherkovich (1966). *S. tenuispina* was identified in this study according to Komárek and Fott (1983).

***Scenedesmus gutwinskii* var. *heterospina* Bodroglkőzy (Figs. 12A-12D)**

**References:** Uherkovich 1966, p 112, pl. XIX, fig. 783; Komárek and Fott 1983, p 918, taf. 247, fig. 4; Hegewald and Silva 1988, p 258, fig. 414.

**Description:** Coenobia are composed of 2-4-8 cells, arranged in a linear series or slightly alternating row along





**Fig. 13.** *Scenedesmus oahuensis* var. *clathratus* f. *longiclathratus*. Scale bars, 10 µm.

the sides. Cells are long, ovoid and ellipsoidal, with conical or rounded poles. One to two teeth spines are found on the poles of the inner cells. The marginal cells have slightly curved or straight spines at one pole and short spines on other pole, with 3-8 straight or slightly convex, short spines on the outermost side. Cells have a single chloroplast, with a pyrenoid. Cells are 8-15 µm long and 3-7 µm wide.

**Occurrence sites:** 1, 6, 7, 8 (Table 1 and Fig. 1).

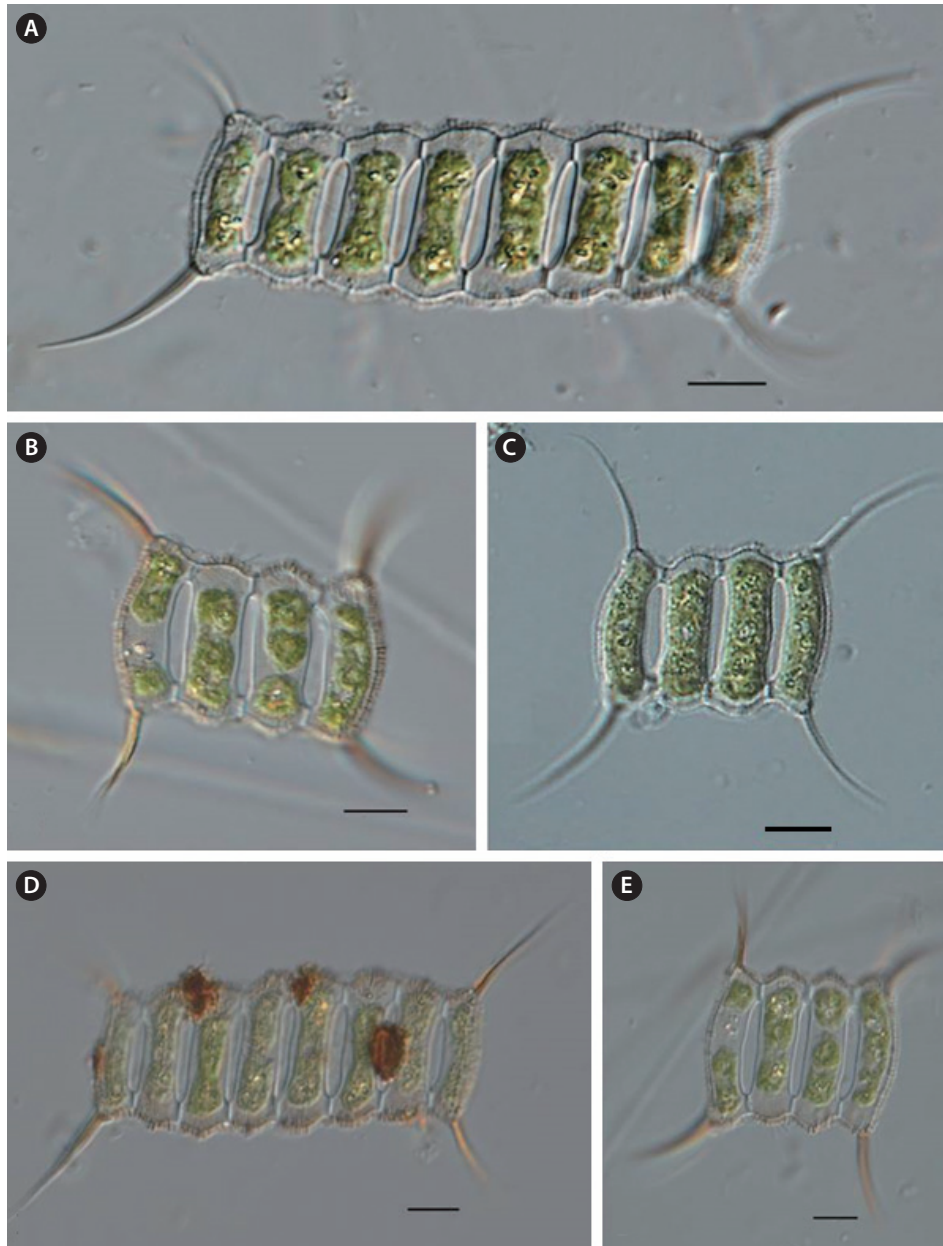
***Scenedesmus oahuensis* var. *clathratus* f. *longiclathratus*  
G. Tell (Figs. 13A-12D)**

(Synonym: *S. oahuensis* var. *longiclathratus*)

**References:** Komárek and Fott 1983, p 936, taf. 251, fig. 5; Hegewald and Silva 1988, p 329, fig. 539.

**Description:** Coenobia are composed of 4-8 cells, arranged in a linear series. Cells are long cylindrical, or ellipsoidal-cylindrical, with conical or rounded poles. The inner cells may have long spines with continuous or interrupted longitudinal ribs at the poles. The marginal





**Fig. 14.** *Scenedesmus oahuensis* var. *clathratus*. Scale bars, 10  $\mu$ m.

cells have a straight or slightly curved long spine at the poles, and the outer side wall of marginal cells are straight or slightly convex. There are distributed granulates on the side and wall of inner and marginal cells. Cells have a single chloroplast, with a pyrenoid. Cells are 25-35  $\mu$ m long and 8-12  $\mu$ m wide.

**Occurrence sites:** 1, 4, 6, 7, 8, 13, 18 (Table 1 and Fig. 1).

**Remarks:** Lemmermann (1905) reported new variety *S. quadricauda* var. *oahuensis* from the samples which were collected at Oahu, Hawaii. The new variety had the

morphological characteristics of cells with rounded poles with distributed granulates on the cell wall and enclosed granulates on sides of the cell. Smith (1916) reported an independent species that had larger cells than *S. quadricauda* with distributed granulates on the cell wall. Hortobagyi (1973) separated this taxon from *S. maximus* on the basis of the spines at the poles with distributed granulates on the sides of the cells. Sieminska (1965) separated *S. oahuensis* var. *montanensis* from *S. oahuensis* because of the two short spines present at the poles of the inner cells,

which were absent in typical ones. These spines were curved downwards, and the cell wall was a continuous longitudinal ridge. Hegewald (1979) separated *S. maximus* from *S. quadricauda* and included *S. oahuensis* var. *granulatus*, *S. oahuensis* var. *montanensis*, *S. oahuensis* var. *symmetricus* into *S. maximus* as synonyms. Komárek and Fott (1983) separated *S. oahuensis* and *S. oahuensis* var. *montanensis* from synonym taxa of Hegewald (1979). Jeon and Hegewald (2006) reported *Desmodesmus tropicus* var. *longiclathratus* on the basis of the basionym of *S. oahuensis* var. *clathratus* f. *longiclathratus*. It is classified with *S. oahuensis* var. *clathratus* f. *longiclathratus* according to Tell (1979) in this study, but further study is needed to merge as a synonym or separate as an independent taxon.

***Scenedesmus oahuensis* var. *clathratus* Manguin (Figs. 14A-14F)**

**References:** Komárek and Fott 1983, p 940, taf. 252, figs. 6-7; Hegewald and Silva 1988, p 329, fig. 539.

**Description:** Coenobia are composed of 4-8 cells, arranged in a linear series with intercellular perforation between cells along the polar region. Cells are long cylindrical or ellipsoidal-cylindrical, spool-shaped with rounded poles. The marginal cells have a straight or slightly curved long spine at the poles, while the outsides of marginal cells are straight or slightly convex. There are distributed granulates on the side and inner wall of marginal cells. Cells have a single chloroplast with a pyrenoid. Cells are 25-35 µm long and 8-12 µm wide.

**Occurrence sites:** 1, 4, 6, 7, 8 (Table 1 and Fig. 1).

**Remarks:** Manguin (1936) reported this taxon on the basis of the figure and description of *Scenedesmus* sp. and *S. ornatus* (Hegewald and Silva 1988). Komárek and Fott (1983) included *S. papillatus*, *S. perforatus* var. *circumcinctus* and *S. perforatus* var. *oahuensioides* into a synonym of this taxon. The former two taxa are similar to *S. oahuensis* var. *clathratus*, but the latter taxon is similar to *S. oahuensis*. It is separated to *S. perforatus* var. *oahuensioides* as the synonym of this taxon in this study. *S. perforatus* has a similar shape to the coenobia of this taxon, but different cell wall with granulates on the sides of the cells. Therefore, this work separated it as an independent species from this taxon and *S. perforatus*.

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