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Nine taxa of newly recorded species of chlorophytes (Chlorophyceae and Trebouxiophyceae, Chlorophyta) in Korea

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Abstract

In this study, we collected, identified, and cultured phytoplankton that inhabited the small-scale artificial wetlands in Danyang-gun of Chungcheungbuk-do and Suwon-si of Gyeonggi-do. From the study, nine newly recorded species, including four genera (*Mychonastes*, *Willea*, *Hindakia,* and *Oocystella*), were found in Korea: *Choricystis guttula*, *Mychonastes densus*, *Willea apiculata*, *Pseudokirchneriella elongata*, *Raphidocelis subcapitata*, *Hindakia tetrachotoma*, *Oocystella nephrocytioides, Oocystis bispora,* and *Oocystis ecballocystiformis*. The morphological characteristics of the nine taxa identified in this study were mostly similar to previously reported characteristics. However, *Oocystella nephrocytioides* were smaller than previously recorded, while *Choricystis guttula* and *Mychonastes densus* were larger than previously recorded.

Key words: Chlorophyceae, newly recorded species, phytoplankton, Trebouxiophyceae

INTRODUCTION

Green algae appear in diverse habitats, including freshwater, brackish water, and terrestrial habitats, and they are used in ecological studies. Some species are considered important in many industries, such as biodiesel, medical, food, and cosmetics (Kim and Chung 1993, Oh et al. 2010, Selvarajan et al. 2015).

Chlorophytina was first named by Chadefaud (1950) and was studied by other scholars who added more species, and continual taxonomic revisions occurred (Park and Adams 1961, Round 1963). Currently, it is a diverse flora, having a total of 5,886 species, including species of the following classes: Chlorodendrophyceae, Chlorophyceae, Pedinophyceae, Trebouxiophyceae, and Ulvophyceae (Chadefaud and Emberger 1960, Round 1963, Guiry and Guiry 2015).

Chlorophyceae and Trebouxiophyceae are usually unicellular or in colonies. The cell morphology and the chloroplast morphology are very diverse, and some species have one to hundreds of flagella. Currently, 746 species of Trebouxiophyceae and 3,363 species of Chlorophyceae have been reported in Algaebase (Guiry and Guiry 2015). In Korea, approximately 400 species of Chlorophyceae were reported by Chung (1993), and newly recorded species are continually found, but the number of species in Korea is low in comparison to the total.

Thus, in this study, phytoplankton inhabiting small-scale artificial wetlands in 2014 were observed. Nine taxa of newly recorded species were added, and the morpho-

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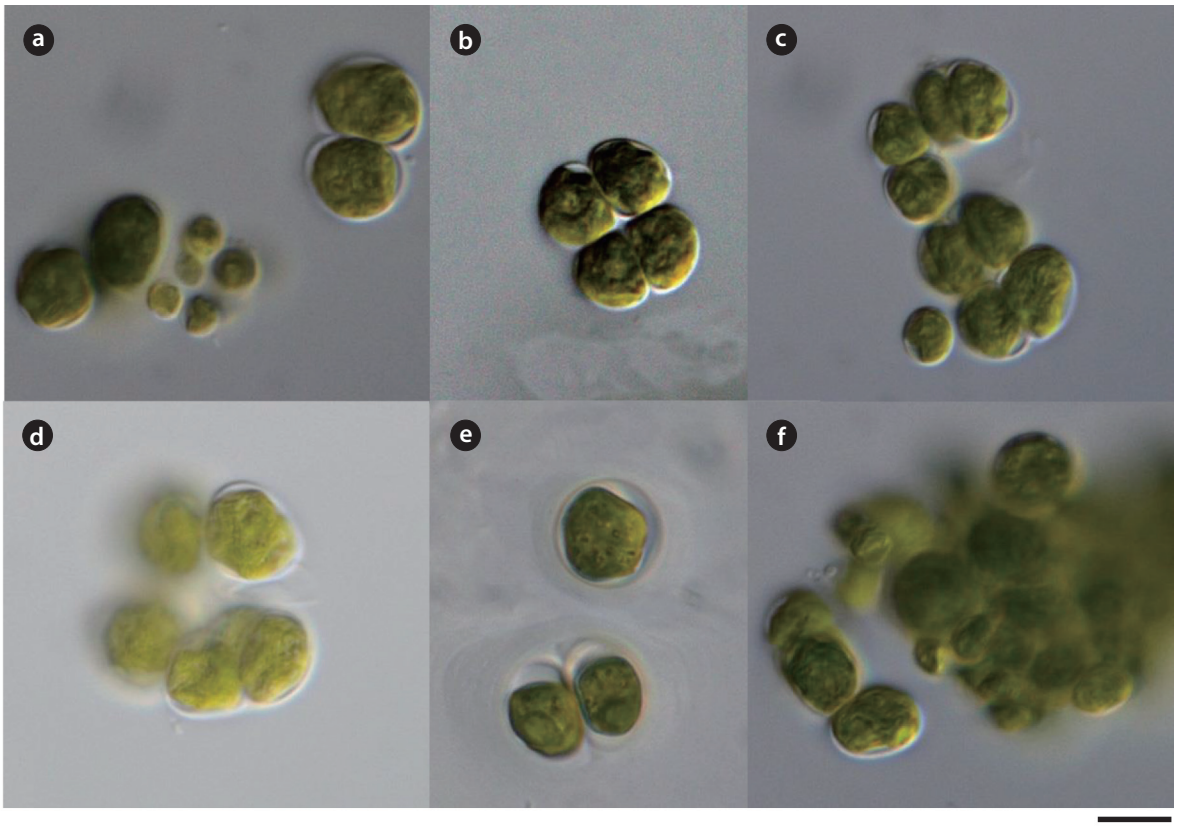

Fig. 1. Microscopic photographs of *Choricystis guttula* Hindák found in this study. Scale bar represents 10 μm.

logical characteristics of the species were recorded to supplement the Korean green algal flora.

MATERIALS AND METHODS

The samples were collected at the artificial wetlands during 2014. One of the collection sites was a small pond at Kyonggi University, Yiui-dong, Suwon-si, Kyonggi-do. The second site was the Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Freshwater algae were collected from phytoplanktonic and periphytic samples using a 25-μm-mesh, 30-cm-diameter phytoplankton net. Each sample was sealed and refrigerated in a light-tight container and transferred to the laboratory. Enriched cultures of aerial algae were made in Bold's basal medium (Stein 1973) and maintained in the algal culture collection of Kyonggi University (ACKU).

The samples were examined at ×400–1,000 magnification under a Zeiss Microscope (Axio Imager A2; Carl Zeiss, Oberkochen, Germany), and photomicrographs were taken with an AxioCam HRC camera (Carl Zeiss).

The taxonomic classification system used was based on Algaebase (Guiry and Guiry 2015) and Komárek and Fott (1983). The taxa were identified based on the work of Prescott (1973), Hindák (1977, 1980, 1984, 1988), Hirose et al. (1977), Komárek (1983), Komárek and Fott (1983), John et al. (2002), and John and Robert (2003). The ecology and distribution of each species were determined by referring to Guiry and Guiry (2015) and Komárek and Fott (1983).

RESULTS AND DISCUSSION

The nine newly added Korean species were *Choricystis guttula*, *Mychonastes densus*, *Willea apiculata*, *Pseudokirchneriella elongata*, *Raphidocelis subcapitata*, *Hindakia tetrachotoma*, *Oocystella nephrocytioides*, *Oocystis bispora*, and *Oocystis ecballocystiformis*. From these species, *Mychonastes*, *Willea*, *Hindakia*, and *Oocystella* were also newly recorded genera.

We describe below the morphological and ecological characteristics of the nine species previously unrecorded in Korea and provide microscopic photographs.

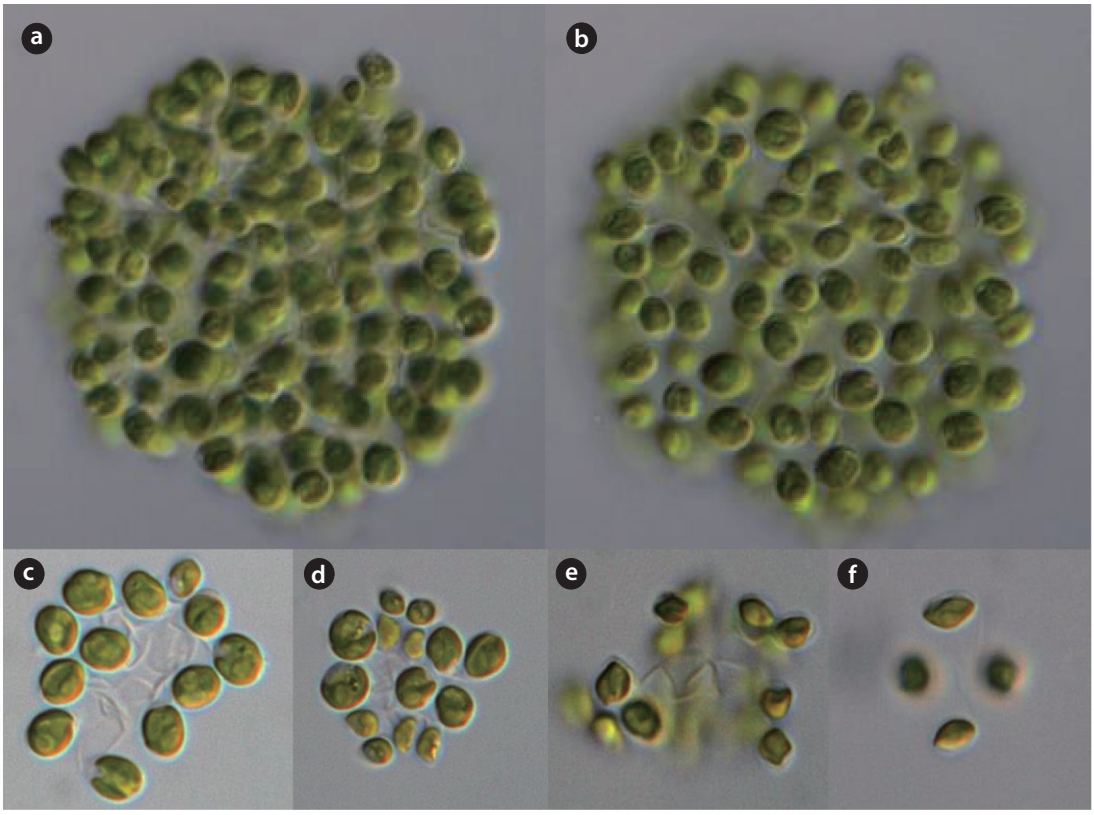

Fig. 2. Microscopic photographs of *Mychonastes densus* (Hindák) Krienitz, C. Bock, Dadheech & Proschold found in this study. Scale bar represents 10 µm.

Phylum Chlorophyta
Subphylum Chlorophytina
Class Chlorophyceae
Order Chlamydomonadales
Family Coccomyxaceae
Genus *Choricystis*

***Choricystis guttula* Hindák 1980 (Fig. 1)**

The cells are elliptical or asymmetrically oval in shape with pointed or wide, round edges. The cell walls are smooth. The cells are found solitary or in colonies of 2–20 cells. Without mucilage, the cell walls are smooth and hyaline. The chloroplasts are parietal troughs without pyrenoids.

The observed cell diameter was 7.7–12.2 µm in this study, larger than that recorded by Hindák (1980) (4.5–6 × 2.5–3 µm).

Ecology and Distribution: Freshwater species; Europe: Romania (Caraus 2012).

Site of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-012.

Order Sphaeropleales
Family Mychonastaceae
Genus *Mychonastes*

The genus *Mychonastes* was named by Simpson and Van Valkenburg (1978). Currently, 21 species are recorded in Algaebase. Members of this genus are planktonic and usually found in fresh water, but some species are also found in terrestrial habitats and estuaries. They are found solitary or in colonies. The cell shape is usually oval. The chloroplasts are single or parietal without pyrenoids. The cell diameter is known to be around 1–30 µm (Guiry and Guiry 2015).

***Mychonastes densus* (Hindák) Krienitz, Bock, Dadheech, Proschold 2011 (Fig. 2)**

Basionym: *Dictyosphaerium densum* Hindák 1984.

Synonym: *Dictyosphaerium densum Hindák 1984*; *Pseudodictyosphaerium densum* (Hindák) Hindák 1988.

The cells are slightly oval to elliptical. Between four and 32 cells are connected in a mucilage strap, forming colonies. Colonies of 64 cells are observed as well. The chloroplasts are cup-shaped and tilted without pyrenoids.

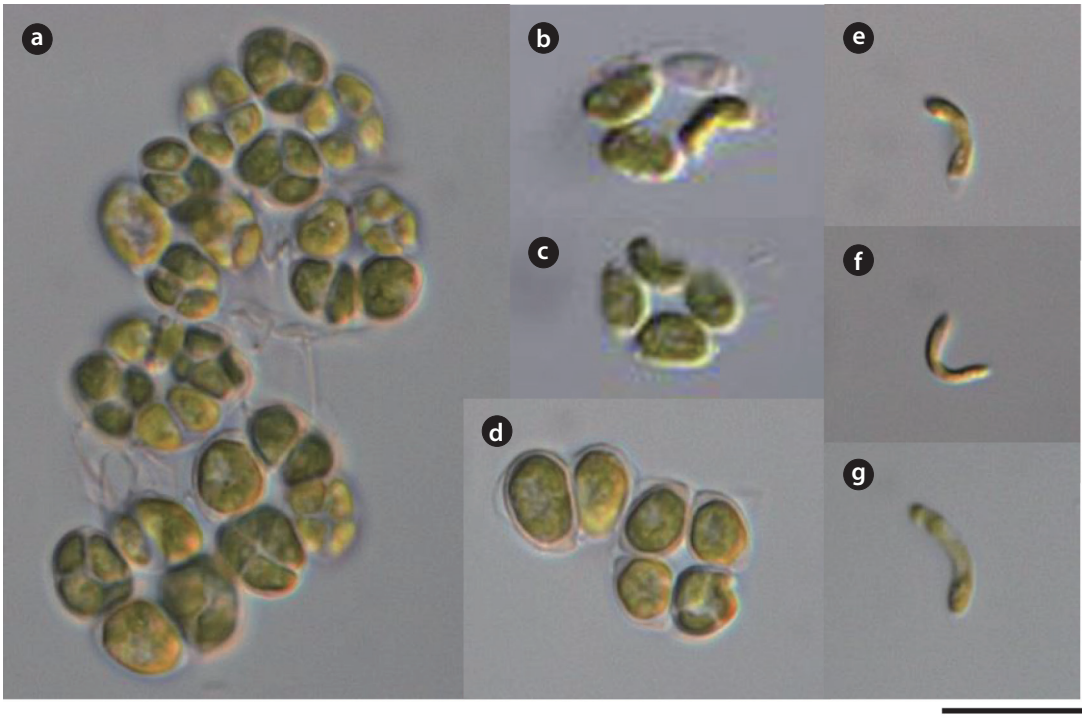

Fig. 3. Microscopic photographs of *Willea apiculata* (Lemmermann) D.M.Jonh, M.J. Wynne & P.M. Tsarenko (a-d) and *Raphidocelis subcapitata* (Korshikov) Nygaard, Komárek, J.Kristiansen & O.M.Skulberg (e-g) found in this study. Scale bar represents 10 μm.

The cell size in this study was found to be 3.4–5.2 μm in length and 2.7–3.5 μm in width, slightly larger than that recorded by Hindák (1984) (2.3–4 × 1.8–3 μm).

Site of collection: A small pond in Yiui-dong, Suwon-si, Kyonggi-do.

Date of collection: October, 2014.

Specimen locality: ACKU 9-013.

Family Scenedesmaceae
Genus *Willea*

The genus *Willea* was named by Schmidle (1900). Currently, nine species are recorded in Algaebase. They are planktonic and found in fresh waters like lakes. Colonies are formed with two or more cells surrounding the mucilage. The cells are usually oval or cylindrical and round on the edges. The cell walls are smooth. The chloroplasts are single or parietal and pyrenoids are present or absent. The cell size is normally in the range of 6–15 × 4–6 μm (Guiry and Guiry 2015).

Willea apiculata (Lemmermann) John, Wynne, Tsarenko 2014 (Fig. 3a-3d)

Basionym: *Staurogenia apiculata* Lemmermann 1898.

Synonym: *Staurogenia apiculata* Lemmermann 1898; *Crucigenia apiculata* (Lemmermann) *Schmidle* 1900; *Tetrastrum apiculatum* (Lemmermann) Schmidle ex Brunnthaler 1915; *Crucigeniella apiculata* (Lemmermann) Komárek 1974.

The cells are irregular (i.e., lengthwise ovals, rounded triangles, and rectangles). The outline is arch-shaped, widely concave, and both ends of the cells are narrow. Four rectangular cells are connected to form an empty trapezoid-shaped space. The cell size is 6.1–8.8 μm in length and 2–5.5 μm in width, similar to the cell size recorded by Hindák (1977) (4–9 × 3–7 μm).

Ecology and Distribution: Freshwater species; Asia: China (Hu and Wei 2006), Russia (Far East) (Medvedeva and Nikulina 2014); North America: Great Lakes (Prescott 1962); South America: Brazil (Freitas and Loverde-Oliveira 2013); Europe: Baltic Sea (Hällfors 2004), Black Sea (BSPC Editorial Board 2014), Britain (John and Tsarenko 2002, Whitton et al. 2003, John et al. 2011), Romania (Caraus 2002, 2012), Spain (Fanés Treviño et al. 2009, Pérez et al. 2010).

Site of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-014.

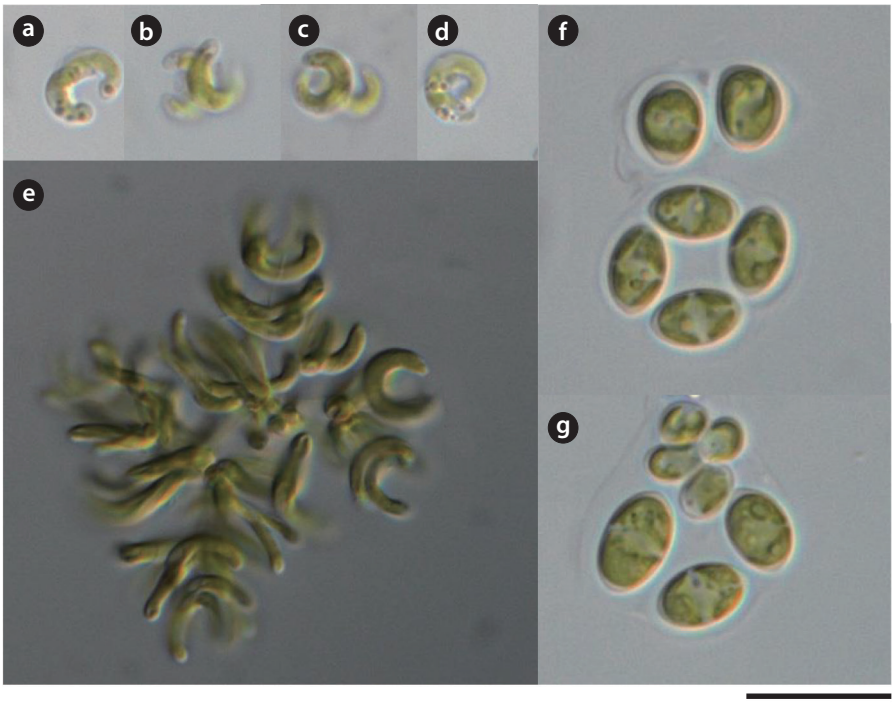

Fig. 4. Microscopic photographs of *Pseudokirchneriella elongata* (G. M. Smith) F. Hindák (a-e) and *Oocystis ecballocystiformis* Iyengar (f, g) found in this study. Scale bar represents 10 μm.

Family Selenastraceae
Genus *Pseudokirchneriella*

***Pseudokirchneriella elongata* (Smith) Hindák 1990 (Fig. 4a-4e)**

Basionym: *Kirchneriella elongate* Smith 1916.

Synonym: *Kirchneriella elongate* Smith 1916; *Kirchneriella contorta* var. *elongate* (Smith) Komárek 1979; *Raphidocelis contorta* var. *elongata* (Smith) Marvan, Komárek, Comas 1984; *Kirchneria elongata* (Smith) Hindák 1988.

The cells are cylindrical but have various shapes, such as C-shape, S-shape, and Screw-shape. The ends of the cells are round. Between 4 and 32 cells make irregular colonies. The chloroplasts are full, without pyrenoids. The cell size is 15.8–18.7 μm in length and 2.7–3.2 μm in width, similar to the cell size recorded by Komárek (1983) (15–30 × 1.5–3 μm).

Ecology and Distribution: Freshwater species; North America: Great Lakes (Prescott 1962); South-west Asia: Pakistan (Mehwish and Aliya 2005), Turkey (Asia) (Soylu and Gönülol 2006); Europe: Romania (Caraus 2002); South America: Argentina (Couté and Tell 2011).

Site of Collection: A small pond in Yiui-dong, Suwon-si, Kyonggi-do.

Date of collection: October, 2014.

Specimen Locality: ACKU 9-024.

Genus *Raphidocelis*

***Raphidocelis subcapitata* (Korshikov) Nygaard, Komárek, Kristiansen, & Skulberg 1987 (Fig. 3e-3g)**

Basionym: *Ankistrodesmus subcapitatus* Korshikov 1953.

Synonym: *Kirchneriella subcapitatus* Korshikov 1953; *Kirchneriella subcapitata* (Korshikov) Hindák 1988; *Pseudokirchneriella subcapitata* (Korshikov) Hindák 1990.

The cells are cylindrical but have various shapes, such as C-shape and S-shape. The ends of cells are rounded. The cells are solitary. The chloroplasts are full, without pyrenoids. The cell size is 12.1–12.6 μm in length and 1.7–2.4 μm in width, similar to the cell size reported by Hindák (1977) (7–23 × 1.2–5 μm).

Ecology and Distribution: Freshwater species; Europe: Britain (John et al. 2011), Romania (Caraus 2002, 2012), Spain (Fanés Treviño et al. 2009), Czech Republic (Stirk et al. 2013), Germany (Krienitz et al. 2011); North America: North Dakota (Fawley et al. 2006); Caribbean Islands: Cuba (Comas González 2008); Asia: Russia (Far East) (Medvedeva and Nikulina 2014).

Sites of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-023.

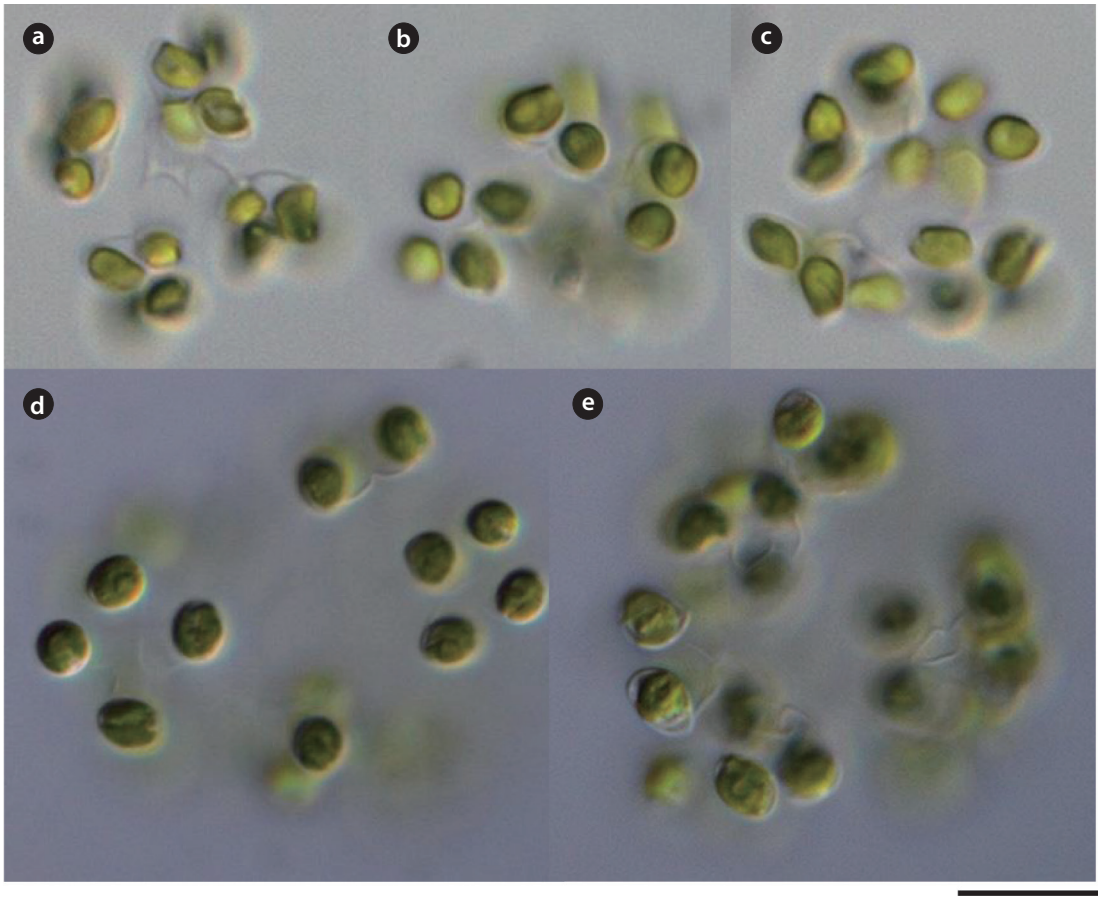

Fig. 5. Microscopic photographs of *Hindakia tetrachotoma* (Printz) C. Bock, Proschold & Kienitz found in this study. Scale bar represents 10 μm.

Class Trebouxiophyceae
Order Chlorellales
Family Chlorellaceae
Genus *Hindakia*

The genus *Hindakia* was named by Bock et al (2010). This genus was divided from the genus *Dictyosphaerium*. Algaebase has accepted two species from this genus.

Planktonic colonies consist of 4–64 cells in the mucilage. The cells are oval to elliptical. The chloroplasts are cup-shaped with pyrenoids (Christina et al. 2010).

Hindakia tetrachotoma (Printz) Bock, Proschold, Kienitz 2010 (Fig. 5)

Basionym: *Dictyosphaerium tetrachotomum* Printz 1914.

Synonym: *Dictyosphaerium pulchellum* var. *ovatum* Korshikov 1953.

The cells are oval to elliptical. Younger cells are longer, and vegetative cells are more oval in shape than younger cells. The mucilage branch is regular and clearly observable. The ends of the cells are connected to the mucilage, making colonies with 4–16 cells. The chloroplasts are cup-shaped with pyrenoids. In this study, the cell size is 4–5.6 μm in length and 2.1–4.3 μm in width, similar to that reported by Hindák (1977) (3–5 × 2–3 μm) and Printz (1914) (6.5–8.5 × 4.5 μm).

Ecology and Distribution: Freshwater species; Europe: Baltic Sea (Hällfors 2004), Britain (John and Tsarenko 2002, Whitton et al. 2003, John et al. 2011), Romania (Caraus 2002, 2012), Spain (Cambra Sánchez et al. 1998, Fanés Treviño et al. 2009, Pérez et al. 2009, 2010).

Site of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-033.

Family Oocystaceae
Genus *Oocystella*

The genus *Oocystella* was named by Lemmermann (1903). Currently, 18 species are reported in Algaebase.

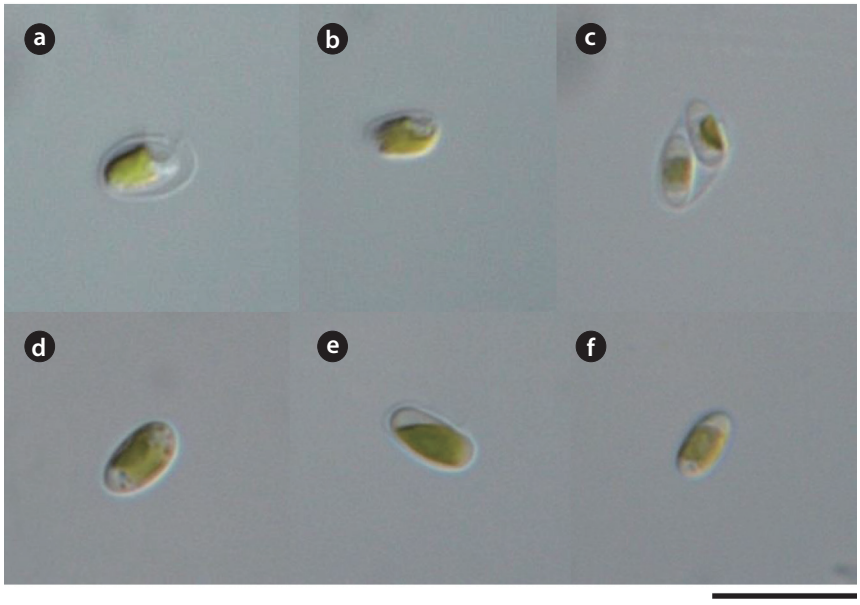

Fig. 6. Microscopic photographs of *Oocystella nephrocytioides* (Forr & Cado) found in this study. Scale bar represents 10 μm.

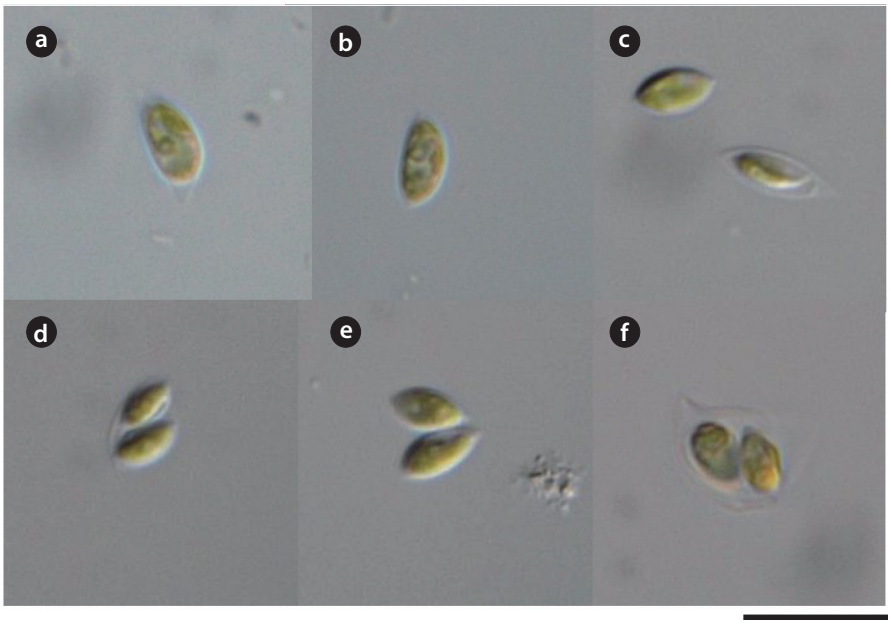

Fig. 7. Microscopic photographs of *Oocystis bispora* Komárek found in this study. Scale bar represents 10 μm.

They are planktonic and usually found in fresh water. Normally, they are solitary, but sometimes they form colonies with 2–16 cells around the mucilage. The cells are usually oval, elliptical, spherical, or in fusiform. The cell walls are smooth. The chloroplasts are in pieces or in parietal, stellate, H-shaped, or bowl-shaped form with pyrenoids. The cell size is normally 4–32 × 2.5–22 μm (Guiry and Guiry 2015).

***Oocystella nephrocytioides* (Forr and Cado) Hindák 1988 (Fig. 6)**

Basionym: *Oocystis nephrocytioides* Fott and Cado 1966.

Synonym: *Kirchneriella nephrocytioides* (Fott and Cado) Hindák 1977.

The cells are elliptical, and the cell walls are smooth. The cells are usually solitary, but some exist in irregular two-cell mucilage colonies. The chloroplasts are usually

empty in one side and tilted, but some have both ends hollow. In this study, the cell diameter is 4–5 μm, and the mucilage size surrounding the cell is 8.1 μm in length and 5 μm in width, smaller than that recorded by Hindák (1977) (cell 10–15 × 4–6 μm, mucilage 5–10 μm).

Ecology and Distribution: Freshwater species; South America.

Site of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-034.

Genus *Oocystis*

Oocystis bispora Komárek 1983 (Fig. 7)

Synonym: *Oocystella bispora* (Komárek) Hindák 1988.

The cells are elliptical and seed-shaped. Both ends are pointed. Two to four cells form colonies in irregular mucilage. One pyrenoid is found in each chloroplast. In this study, the cell size is 8 μm in length and 2.6–4.5 μm in width, similar to that reported by Komárek (1983) (3.8–8 × 2.2–4.6 μm).

Ecology and Distribution: Freshwater species.

Sites of Collection: Gadae eco-wetland in Gadae-ri, Danyang-gun, Gagok-myeon, Chungcheongbuk-do.

Date of collection: September, 2014.

Specimen Locality: ACKU 9-035.

Oocystis ecballocystiformis Iyengar 1932 (Fig. 4f and 4g)

The cells are irregular and have various shapes, such as oval and asymmetrical elliptical. The cell walls are smooth. Between two and four cells surround the mucilage, forming colonies. The chloroplasts are divided in four parts and have cell walls. The centers are cross-shaped and empty, and many pyrenoids are found. In this study, the cell size is 6.4–10.22 μm in length and 4.83–5.91 μm in width, similar to that reported by Komárek (1983) (8–24 × 3.5–9.1 μm).

Ecology and Distribution: Europe: Portugal (Cambra Sánchez et al. 1998).

Site of Collection: A small pond in Yiui-dong, Suwon-si, Kyonggi-do.

Date of collection: October, 2014.

Specimen Locality: ACKU 9-025.

The nine observed species had small cells, mainly oval to elliptical in shape. Some were rectangular or arch-shaped. Two or more cells surrounded the mucilage or were connected, forming colonies. These morphological characteristics were similar to those of previously recorded species, but *Choricystis guttula* and *Mychonastes densus* were found to be larger in cell size, and *Oocystella nephrocytioides* was observed to have smaller cells than the recorded species.

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