



# New records of the genus *Spirogyra* (Zygnemataceae, Conjugatophyceae) in Korea

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## Abstract

*Spirogyra* is a zygnematalean green algal genus that is ubiquitous in a broad range of freshwater habitats throughout the world. Samples collected throughout Korea from October 2004 to July 2015 were examined using light microscopy. Morphological characteristics (e.g., size of vegetative cells, number of chloroplasts in each cell, type of end walls of adjacent cells, details of conjugation, shape of female gametangia, dimensions and shape of zygospores, color and ornamentation of median spore walls) were used as diagnostic characteristics for species identification. In this study, five species of *Spirogyra* (i.e., *S. emilianensis* Bonhomme, *S. jaoensis* Randhawa, *S. pascheriana* Czurda, *S. weberi* var. *farlowii* (Transeau) Petlovany, and *S. weberi* var. *grevilleana* (Hassall) Kirchner) were described as newly recorded in Korea.

**Key words:** Conjugation, *Spirogyra*, taxonomy, Zygnematales, zygospore

## INTRODUCTION

*Spirogyra* (Link 1820) is an unbranched filamentous green algal genus that is ubiquitous in a broad range of freshwater habitats, including roadside ditches, streams, irrigation canals, marshes, and lakes (Graham et al. 2009). The genus is one of the most ecologically important primary producers in aquatic food webs (Stancheva et al. 2013). The slimy free-floating mats of this type of algae occur frequently in stagnant water bodies during early spring and summer (Gerrath 2003). The genus is characterized by cylindrical cells containing spiral or ribbon-like chloroplasts, nuclei suspended by threads of cytoplasm, and sexual reproduction by fusion of amoeboid gametes (Transeau 1951).

More than 500 species have been described worldwide by taxonomic studies (Transeau 1951, Randhawa 1959, Yamagishi 1966, Jao and Hu 1978, Kadlubowska 1984, Rundina 1998, Devi and Panikkar 1994, Guiry and Guiry

2015). Morphological features (e.g., size of vegetative cells, number of chloroplasts per cell, end wall type of adjacent cells, detailed characteristics of sexual reproduction and female gametangia, size and shape of zygospores, and ornamentation of mature zygospore walls) are used as diagnostic criteria for species identification (Transeau 1951, Randhawa 1959, Kadlubowska 1984). However, morphological variations of vegetative filament width and number of chloroplasts at different ploidy levels have been reported in clonal-cultured and field-collected materials (McCourt et al. 1986, Wang et al. 1986). Vegetative filaments of the genus are common throughout the year, but reproductive filaments are rarely found in short periods (Transeau 1951, Stancheva et al. 2013). Therefore, it is difficult to identify the species due to their variations in some features of vegetative filaments and the rarity of fertile filaments in nature.

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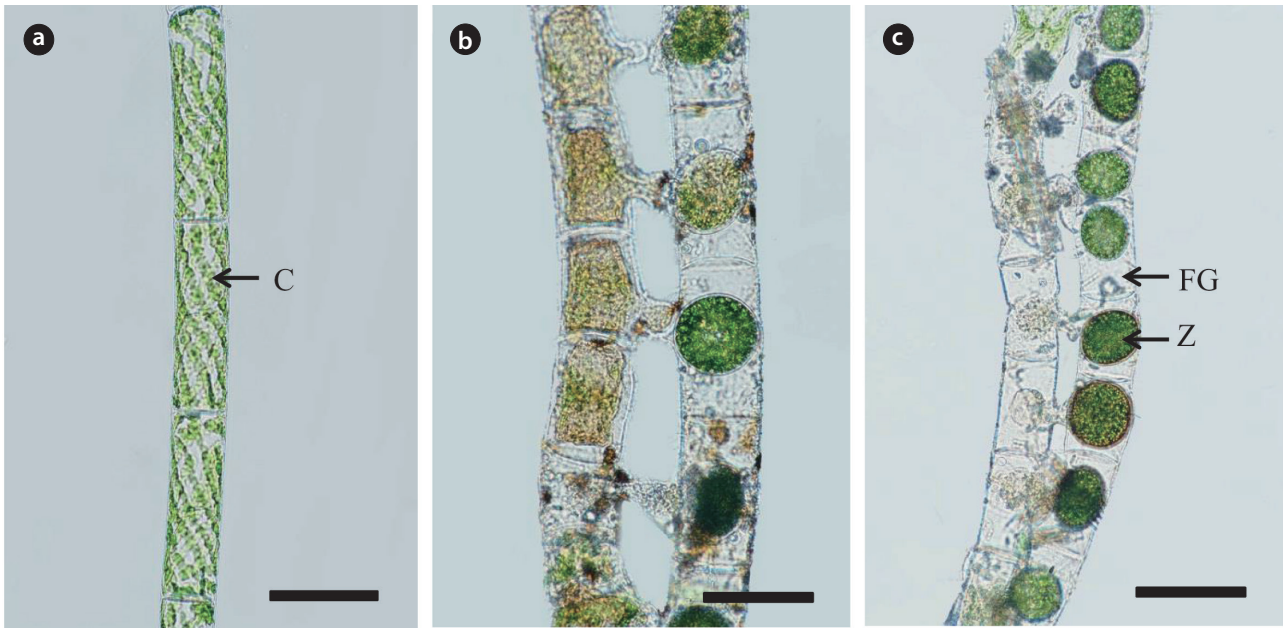
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**Fig. 1.** *Spirogyra emilianensis* Bonhomme: (a) vegetative filament with plane end walls of adjacent cells, (b) scalariform conjugation between two filaments, and (c) cylindrical female gametangia and ovoid or spherical zygospores (C, chloroplast; FG, female gametangium; Z, zygospore). Scale bars represent 100  $\mu\text{m}$  (a and c) and 75  $\mu\text{m}$  (b).

To date, 55 species of *Spirogyra* have been recorded in Korea by floristic studies on local populations (Chung 1968, 1970, 1993) and a morphological study (Kim et al. 2004). However, studies on the diversity, distribution, taxonomy, and relative importance of the genus in Korea are lacking. In this study, the morphological characteristics of *Spirogyra* samples collected from various water bodies throughout Korea were examined in order to add unrecorded species from Korea.

## MATERIALS AND METHODS

Samples were collected from various freshwater habitats throughout Korea from October 2004 to July 2015. To induce sexual reproduction, vegetative filaments of each collection were incubated in modified Reichart/Grote medium devoid of a nitrogen source (Simons et al. 1984). Cultures were maintained in a growth chamber at  $10\text{--}25^{\circ}\text{C} \pm 1^{\circ}\text{C}$  and a 16:8-hour light:dark photoperiod under irradiance of  $30\text{--}50 \mu\text{mol m}^{-2} \text{sec}^{-1}$  (Stein 1973). Fresh fertile materials, field collected or clonal cultured, were used for the morphological study. Photographs were taken using a light microscope (Nikon Optiphot, Tokyo, Japan) equipped with a UFX-II camera (Nikon). Identification of the genus *Spirogyra* was based on the classification sys-

tem of Transeau (1951), Randhawa (1959), Kadlubowska (1984), Johnson (2002), and Algaebase (Guiry and Guiry 2015).

## RESULTS AND DISCUSSION

In the present study, five species of *Spirogyra* (i.e., *S. emilianensis* Bonhomme, *S. jaoensis* Randhawa, *S. pascheriana* Czurda, *S. weberi* var. *farlowii* (Transeau) Petlovany, and *S. weberi* var. *grevilleana* (Hassall) Kirchner) were described as newly recorded in Korea (Table 1).

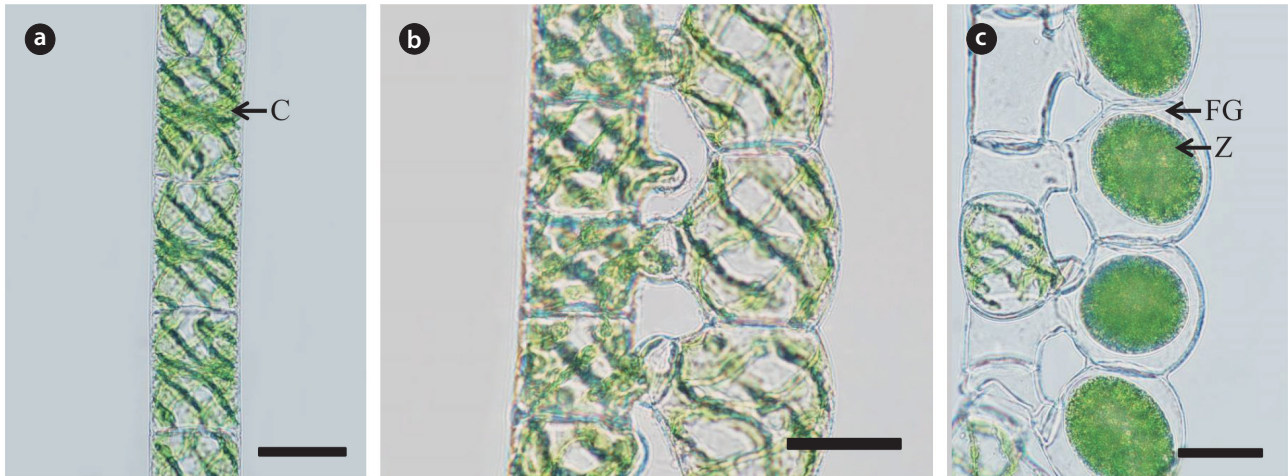
### Class Conjugatophyceae Order Zygnematales Family Zygnemataceae Genus *Spirogyra* Link 1820

#### *Spirogyra emilianensis* Bonhomme 1858 (Fig. 1)

**References:** Bonhomme 1858, p. 7, pl. 2, fig. 2; Transeau 1951, p. 174, pl. 27, fig. 12; Randhawa 1959, p. 404, fig. 480; Kadlubowska 1984, p. 303, fig. 462.

**World distribution:** France, South-west Asia, United States of America.

**Collection site:** Stagnant pool, Donghae, Korea (October 28, 2004).



**Fig. 2.** *Spirogyra jaoensis* Randhawa: (a) vegetative filament with plane septa, (b) early stage of ladder-like conjugation between two filaments, and (c) inflated female gametangia on both sides and ovoid zygospores (C, chloroplast; FG, female gametangium; Z, zygospore). Scale bars represent 50  $\mu\text{m}$  (a-c).

**Description:** The plants are unbranched filaments of cylindrical cells with plane end walls of adjacent cells (Fig. 1a). The cells have four or five chloroplasts containing numerous disc-like pyrenoids, and each chloroplast makes 1.5–2 turns. The vegetative cells are 50–53  $\mu\text{m}$  in width and 80–90  $\mu\text{m}$  in length. Sexual reproduction is scalariform (ladder-like) conjugation (Fig. 1b). Conjugation tubes are formed by both gametes. Zygospores are formed in the receptive (female) gametangial cells, which remain cylindrical (Fig. 1c). Zygospores are ovoid or rarely spherical and 45–60  $\mu\text{m}$  wide and 50–65  $\mu\text{m}$  long. The median spore walls are smooth and brown at maturity.

**Remarks:** *Spirogyra emilianensis* was described by Bonhomme (1858) based on the vegetative cell size, type of cross walls, number of chloroplasts, scalariform conjugation, shape of female gametangia, and size and shape of zygospores. The Korean specimen accords well with the descriptions of *S. emilianensis*, except the spherical zygospores.

*Spirogyra emilianensis* has morphological characteris-

tics that are similar to those of *S. distenta* Transeau and *S. siamensis* Transeau (Transeau 1951, Randhawa 1959, Kadlubowska 1984), such as plane cross walls, scalariform conjugation, cylindrical female gametangia, ovoid zygospores, and smooth mesospores. However, *S. distenta* has two chloroplasts in each cell, inflated sterile cells, and 48–52  $\mu\text{m}$  wide vegetative cells, while *S. siamensis* has three chloroplasts per cell and 46–50  $\mu\text{m}$  wide vegetative cells. This species is distinguished by its vegetative cell width, number of chloroplasts, cylindrical female gametangia, and ovoid zygospores.

#### *Spirogyra jaoensis* Randhawa 1938 (Fig. 2)

**References:** Randhawa 1938, pp. 358-359, fig. 53; Transeau 1951, p. 177; Randhawa 1959, p. 327, fig. 314.

**World distribution:** India.

**Collection sites:** Osip Stream, Yeongdeok, Korea (October 29, 2004) and Chuksan Stream, Yeongdeok, Korea (October 29, 2004).

**Description:** The plants are unbranched filaments of

**Table 1.** Information on the five species of *Spirogyra* described as newly recorded from Korea in this study

Taxa	Collection		Latitude and longitude
	date	site	
<i>Spirogyra emilianensis</i>	28 Oct 2004	Donghae, Korea	37°28'39.3" N, 129°09'23.4" E
<i>S. jaoensis</i>	29 Oct 2004	Yeongdeok, Korea	36°23'25.5" N, 129°22'11.7" E
	29 Oct 2004	Yeongdeok, Korea	36°30'32.3" N, 129°24'23.9" E
<i>S. pascheriana</i>	30 Apr 2010	Haenam, Korea	34°28'36.2" N, 126°37'00.4" E
<i>S. weberi</i> var. <i>farlowii</i>	30 Apr 2010	Haenam, Korea	34°28'04.7" N, 126°39'52.0" E
<i>S. weberi</i> var. <i>grevilleana</i>	29 Oct 2004	Yeongdeok, Korea	36°30'32.3" N, 129°24'23.9" E

cylindrical cells with plane end walls of adjacent cells (Fig. 2a). The cells have five chloroplasts with discoid pyrenoids, and each chloroplast makes 1.0–1.5 turns. The vegetative cells are 50–55 µm in width and 80–200 µm in length. Sexual reproduction is ladder-like conjugation (Fig. 2b). The conjugation tubes are formed by both gametes. The zygospores are formed in the female gametangial cells that become inflated on both sides and are very short (Fig. 2c). The zygospores are ovoid and 50–60 µm wide and 75–90 µm long. The median spore walls are smooth and brown at maturity.

**Remarks:** *Spirogyra jaoensis* was described as *jaoense* by Randhawa (1938) based on the vegetative cell size, plane cross walls, four to six chloroplasts in each cell, scalariform conjugation, slightly swollen female gametangia, oval to elliptical zygospores, and size and wall structure of zygospores. The Korean specimens agree well with the previous descriptions of *S. jaoensis*, except that the female gametangia are inflated on both sides.

*Spirogyra jaoensis* is very similar to *S. emilianensis* Bonhomme in vegetative cell width, number of chloroplasts, plane cross walls, and smooth median spore walls (Randhawa 1959, Transeau 1951). However, this species is characterized by inflated female gametangia on both sides.

#### ***Spirogyra pascheriana* Czurda 1932 (Fig. 3)**

**References:** Czurda 1932, p. 150, fig. 149; Transeau 1951, p. 204, pl. 35, figs. 12-13; Randhawa 1959, p. 380, fig. 423; Kadlubowska 1984, p. 456, fig. 707.

**World distribution:** Czechoslovakia, Slovenia, Spain, United States of America.

**Collection site:** Stagnant pool, Haenam, Korea (April 30, 2010).

**Description:** The plants are unbranched filaments of cylindrical cells with replicate end walls of adjacent cells (Fig. 3a). The cells have a single chloroplast that makes 4.0–5.5 turns. The vegetative cells are 17–20 µm in width and 135–145 µm in length. Sexual reproduction is mainly lateral conjugation (Fig. 3b) and rarely scalariform (Fig. 3c). The conjugation tube is formed mostly by the male gametangium in scalariform. Zygospores are formed in the receptive gametangial cells that become cylindrically inflated (Fig. 3d). Zygospores are ellipsoid and 30–43 µm wide and 63–75 µm long. The median spore walls are smooth and yellow-brown at maturity.

**Remarks:** *Spirogyra pascheriana* was described by Czurda (1932) based on the vegetative cell size, replicate cross walls, one chloroplast in each cell, lateral and scalariform conjugation, cylindrically inflated female gametangia, and size, shape, and wall structure of zygospores.

The Korean specimen accords well with the previous description of *S. pascheriana*, except that the width of the zygospores is narrower than the original description (45–50 µm) of the species. This species is distinguished by mostly lateral conjugation, cylindrically inflated female gametangia, a tube formed by only male gametangia, ellipsoid zygospores, and a 18–21 µm vegetative cell width.

*Spirogyra pascheriana* is comparable to *S. cylindrica* (Hassall) Kützing in terms of the single chloroplast per cell, reticulate end walls of adjacent cells, lateral and scalariform conjugation, a conjugation tube formed by only male gametangia, cylindrically inflated fertile cells, ellipsoid zygospores, and smooth median spore walls (Transeau 1951, Kadlubowska 1984). However, *S. cylindrica* has a narrow filament width (13–16 µm) and small zygospores (22–32 µm in width).

#### ***Spirogyra weberi* var. *farlowii* (Transeau) Petlovany 2015 (Fig. 4)**

**Basionym:** *Spirogyra farlowii* Transeau 1915

**Synonym:** *Spirogyra farlowii* Transeau 1915

**References:** Transeau 1915, p. 29; Transeau 1951, p. 204, pl. 1, fig. 3; Randhawa 1959, p. 360, fig. 382; Kadlubowska 1984, p. 449, fig. 695; Petlovany 2015, p. 60.

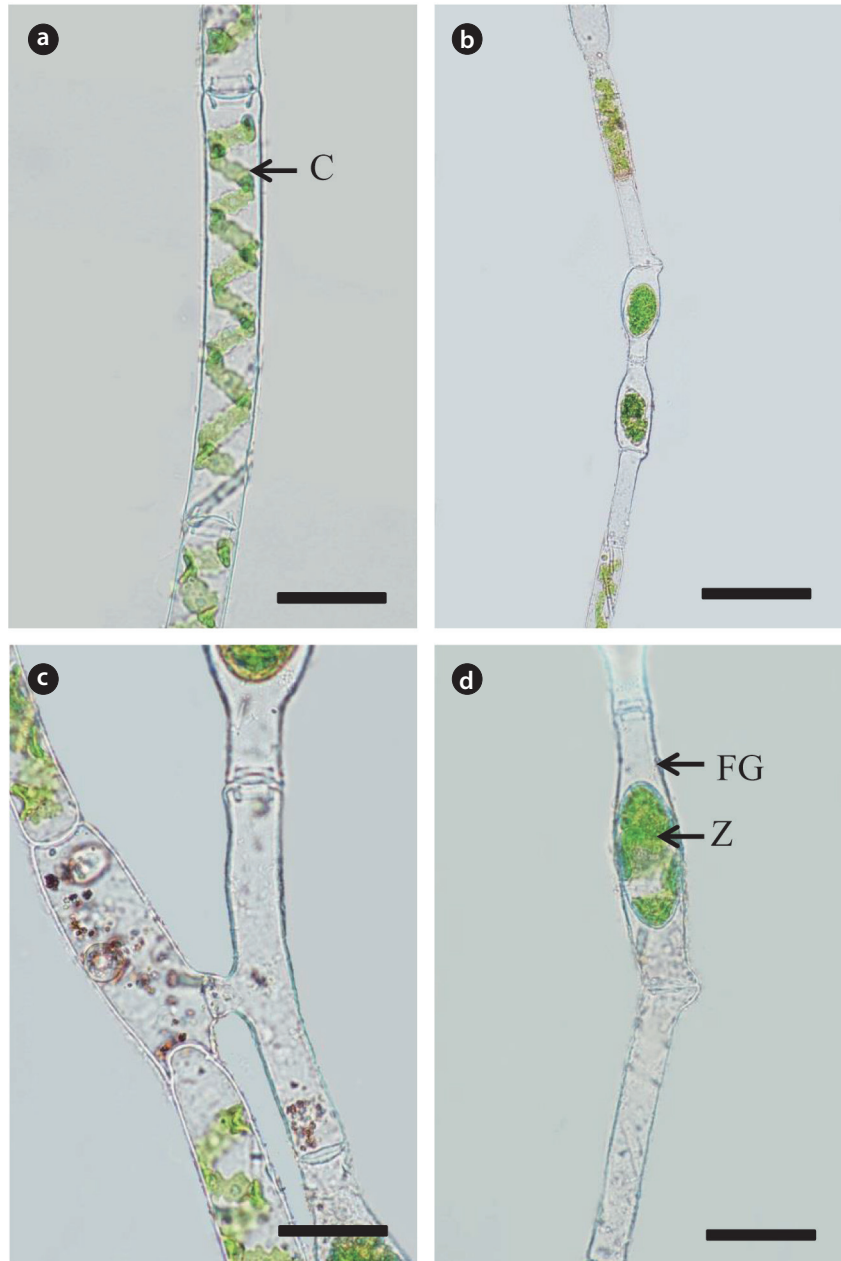
**World distribution:** India, Spain, United States of America.

**Collection site:** Paddy field, Haenam, Korea (April 30, 2010).

**Description:** The plants are unbranched filaments of long cylindrical cells with replicate end walls of adjacent cells (Fig. 4a). The cells have a single ribbon-like chloroplast that makes 3.5–5.0 turns. The vegetative cells are 23–25 µm in width and 530–550 µm in length. Sexual reproduction is scalariform conjugation (Fig. 4b). The conjugation tubes are formed by both gametangia. The zygospores are formed in the female gametangial cells that become inflated on both sides (Fig. 4c). The zygospores are ovoid to ellipsoid and 38–40 µm wide and 50–68 µm long. The median spore walls are smooth and brown at maturity.

**Remarks:** *Spirogyra farlowii* was first described by Transeau (1915) based on the vegetative cell size, replicate end walls, single (rarely two) chloroplast in each cell that makes 2.5–6 turns, inflated fertile cells, shape and size of zygospores, and smooth median spore walls. Transeau (1951) later added features such as scalariform and lateral conjugation and conjugation tubes formed by both cells. Recently, *S. farlowii* was treated as a homotypic synonym of *S. weberi* var. *farlowii* by Petlovany (2015).

The Korean specimen accords well with the previous



**Fig. 3.** *Spirogyra pascheriana* Czurda: (a) vegetative filament with replicate end walls of adjacent cells, (b) lateral conjugation between two cells, (c) early scalariform conjugation between two filaments, and (d) cylindrically inflated female gametangium and ellipsoid zygospore (C, chloroplast; FG, female gametangium; Z, zygospore). Scale bars represent 40  $\mu\text{m}$  (a and c), 100  $\mu\text{m}$  (b), and 55  $\mu\text{m}$  (d).

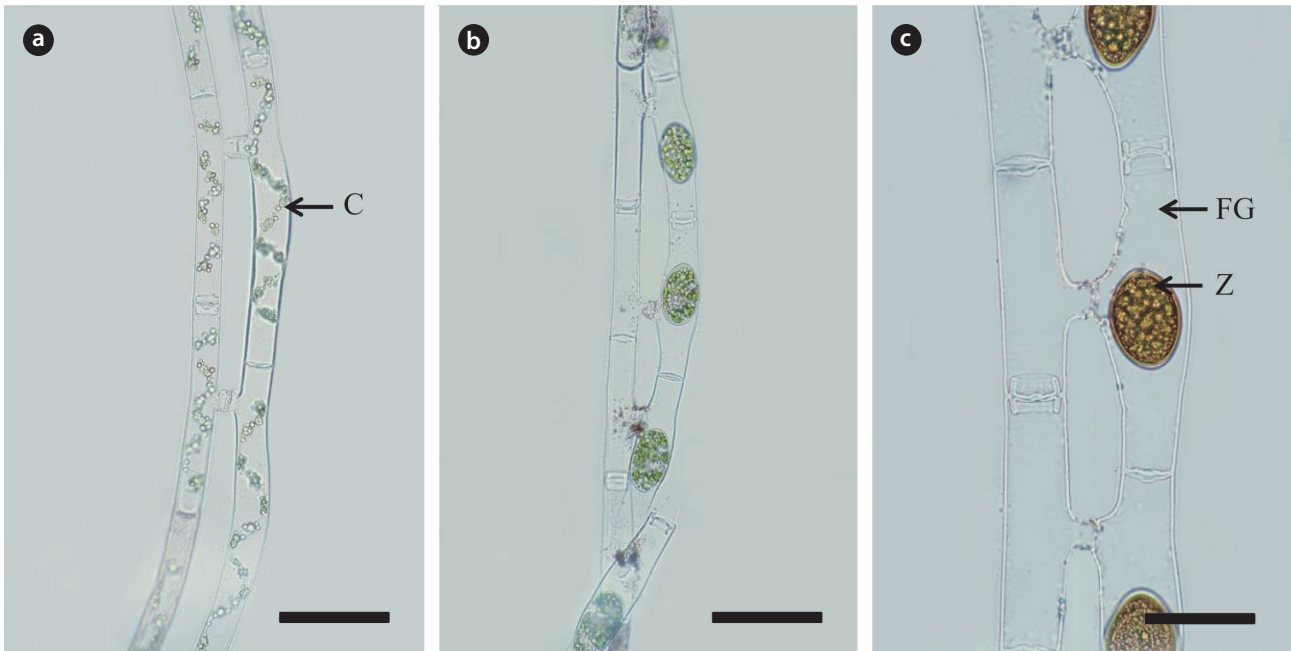
descriptions of *S. farlowii* by Transeau (1915, 1951) except for the lateral conjugation and length of the vegetative cells. It is distinguished by the fusiform inflated female gametangia, more or less long fertile cells, ellipsoid zygospores with pointed ends, conjugation tubes formed by both gametes, and the 23–25  $\mu\text{m}$  vegetative cell width.

***Spirogyra weberi* var. *grevilleana* (Hassall) Kirchner 1878 (Fig. 5)**

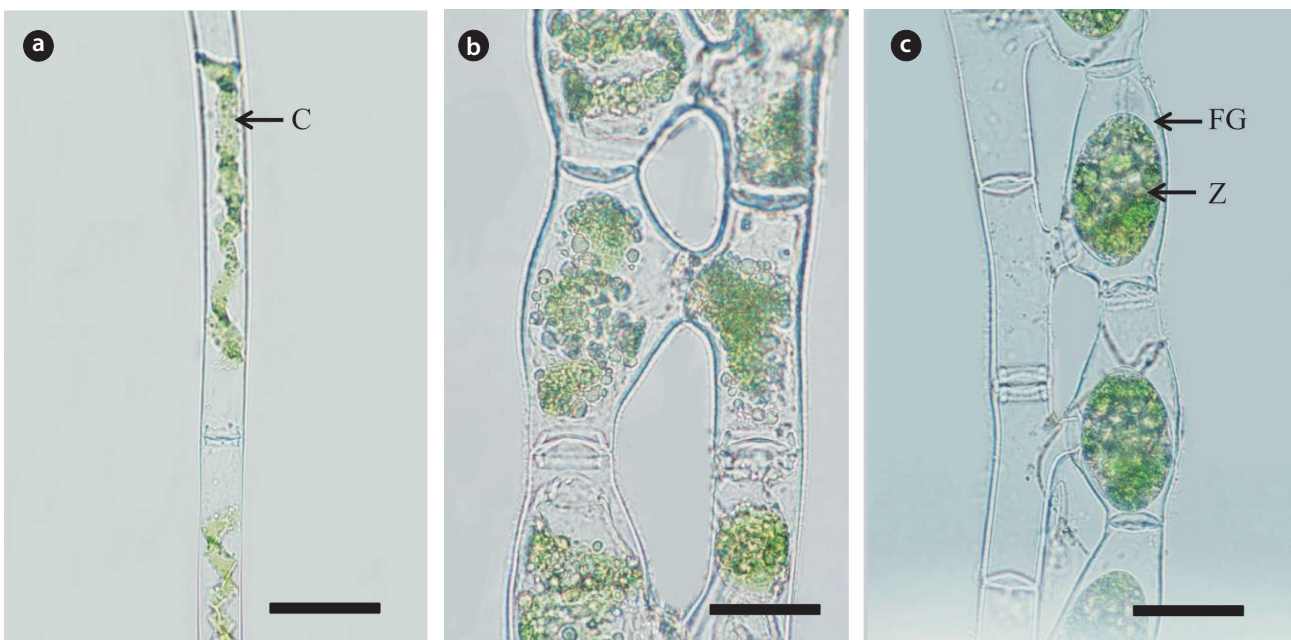
**Basionym:** *Zygnema grevilleanum* Hassall 1842

**Synonym:** *Spirogyra grevilleana* (Hassall) Kützing 1849

**References:** Kützing 1849, p. 438; Kirchner 1878, p. 120; Czurda 1932, p. 151, fig. 150; Transeau 1951, p. 205, pl. 35, figs. 19-20; Randhawa 1959, p. 361, fig. 384; Kadlubowska



**Fig. 4.** *Spirogyra weberi* var. *farlowii* (Transeau) Petlovany: (a) early conjugation between two filaments showing the replicate septa, (b) zygosporangia formed in the receptive gametangia, and (c) inflated female gametangium on both sides and ovoid to ellipsoid zygosporangia (C, chloroplast; FG, female gametangium; Z, zygosporangium). Scale bars represent 100  $\mu\text{m}$  (a and b) and 40  $\mu\text{m}$  (c).



**Fig. 5.** *Spirogyra weberi* var. *grevilleana* (Hassall) Kirchner: (a) vegetative filament with replicate septa, (b) early scalariform conjugation between two filaments, (c) inflated female gametangia on both sides and ovoid to ellipsoid zygosporangia (C, chloroplast; FG, female gametangium; Z, zygosporangium). Scale bars represent 60  $\mu\text{m}$  (a), 30  $\mu\text{m}$  (b), and 40  $\mu\text{m}$  (c).

1984, p. 453, fig. 703; Rundina 1998, p. 284, pl. 124, figs. 4-6; Johnson 2002, p. 497, pl. 126B.

**World distribution:** Australia, Balearic Islands, Brazil, Britain, China, Punjab, Romania, Slovenia, Spain, United States of America.

**Collection site:** Chuksan Stream, Yeongdeok, Korea (October 29, 2004).

**Description:** The plants are unbranched filaments of cylindrical cells with replicate end walls of adjacent cells (Fig. 5a). The cells have a single chloroplast that makes 3.5–4.5 turns. The vegetative cells are 20–23 µm in width and 90–100 µm in length. Sexual reproduction is scalariform (Fig. 5b). The conjugation tube is developed largely by the male gametangium. The zygospores are formed in the receptive gametangial cells that become inflated up to 34–40 µm (Fig. 5c). The zygospores are ovoid to ellipsoid and 40–42 µm wide and 65–75 µm long. The median spore walls are smooth and yellow at maturity.

**Remarks:** *Zygnema grevilleanum* (Hassall 1842) was transferred to the genus *Spirogyra*, *S. grevilleana*, by Kützing (1849). *Spirogyra grevilleana* was treated as a variety of *S. weberi* by Kirchner (1878) based on the size of the vegetative cells, single chloroplast per cell, shape and size of the zygospores. After that, *S. weberi* var. *grevilleana* (Hassall) Kirchner was described as *S. grevilleana* (Hassall) Czurda 1930 (Czurda 1932). However, since Czurda (1932), *S. grevilleana* (Hassall) Kützing has been widely used and reported from many countries (Kadlubowska 1984, Rundina 1998, Johnson 2002, Drummond et al. 2005, Stancheva et al. 2013). Recently, *S. grevilleana* (Hassall) Kützing was treated as a synonym of *S. weberi* var. *grevilleana* (Hassall) Kirchner by Petlovany (2015).

The Korean specimen accords well with the previous descriptions of *S. grevilleana* except for the lateral conjugation. This species is distinguished by inflated female gametangia, ovoid zygospores, a tube formed by largely male gametangium, and a 21–25 µm vegetative cell width.

## ACKNOWLEDGEMENTS

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