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Morphology and Anatomy of *Chorda filum* (Linnaeus) Stackhouse (Chordaceae, Phaeophyta) in Korea

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The morphology and the anatomy of *Chorda filum* (Linnaeus) Stackhouse have been made with special reference to the plants from Oeyeondo, Chujado, and Namhaedo, Korea. The plants are simple, terete, chord-like, tapering toward both ends, and with a small discoid holdfast composed of compact rhizoids. The plant has a meristoderm of single-celled layer, cortex of six- or seven-celled layer, medulla of two- or three-celled layer, and an internal lumen. The meristodermal cells are small, ellipsoid, densely pigmented, and with a rather thinner wall. The cortical cells are long, cylindrical, and have a much thick wall with numerous pits. The medullae are constructed with long hyaline hyphae with inflated tips and immersed in an amorphous and transparent matrix. Most of the surface of a mature plant is covered with the mixture of sporangia and paraphyses. Sporangia and paraphyses are born on meristodermal cells. Paraphyses are short clavate with inflated tips. *C. filum* occurs in all of the Korean waters.

Key Words: anatomy, *Chorda filum*, morphology

INTRODUCTION

The genus *Chorda* was established by Stackhouse (1801, p. xxiv) on the basis of the species *Fucus filum* Linnaeus (1753, p. 1162) with the characteristics "*Fructificatio mucosa in cavitate frondis cylindricae: seminulis glomeratis, nudis cuti adhaerentibus.*" Several species in the genus were introduced since Stackhouse (1801); i.e., *C. lomentaria* Lyngbye (1819, p. 74), *C. tomentosa* Lyngbye (1819, p. 74), *C. capensis* Kützing (1843, p. 334), *C. lessonii* Kützing (1849, p. 549), *C. durvillae* Kützing (1849, p. 549), *C. rimosa* Montagne (cf. Kützing 1849, p. 548), and *C. abreviata* Areschoug 1875, p. 15). *C. lomentaria* Lyngbye became the type species of the genus *Scytosiphon* (C. Agardh 1820, p. 162). *C. capensis* Kützing, *C. lessonii* Kützing, *C. durvillae* Kützing, and *C. rimosa* Montagne were removed to other genera (J. Agardh 1848, p. 127; De Toni 1895, p. 320). Consequently, only the two species, *C. filum* and *C. tomentosa*, are currently recognized in the genus *Chorda* (Christensen 1980-1994; Bold and Wynne 1985). Maier (1984) elucidated a rather distant relationship between *C. tomentosa* and *C. filum* in the points that the sporophytes of the former had long assimilative filaments on the surface, while those of the latter had phaeophycean hairs, and the gametophytes of the former was monoecious, while those of the latter dioecious.

Many floristic or ecological studies revealed the occurrences of *C. filum* in Korean waters (Fig. 1). However, the morphology and the anatomy of this species have not been made with Korean plants, although the morphology as well as life history of *C. filum* were made with the plants in other seas in rather details (Reinke 1892; Kylin 1933 etc.). Consequently, the morphological and the anatomical characteristics of *C. filum* are to be made with reference to the plants from Korea in order to provide the comprehensive knowledge of this species.

MATERIALS AND METHODS

The plants have been collected at the subtidal zone as well as rock pools from Namhaedo (Sachon) and Chujado (Sinyang) in the southern coast and from Oeyeondo in the western coast of Korea. The plants from Namhaedo were preserved in 5% formalin seawater in the field and mounted on herbarium sheets after morphological and anatomical examination. Some plants

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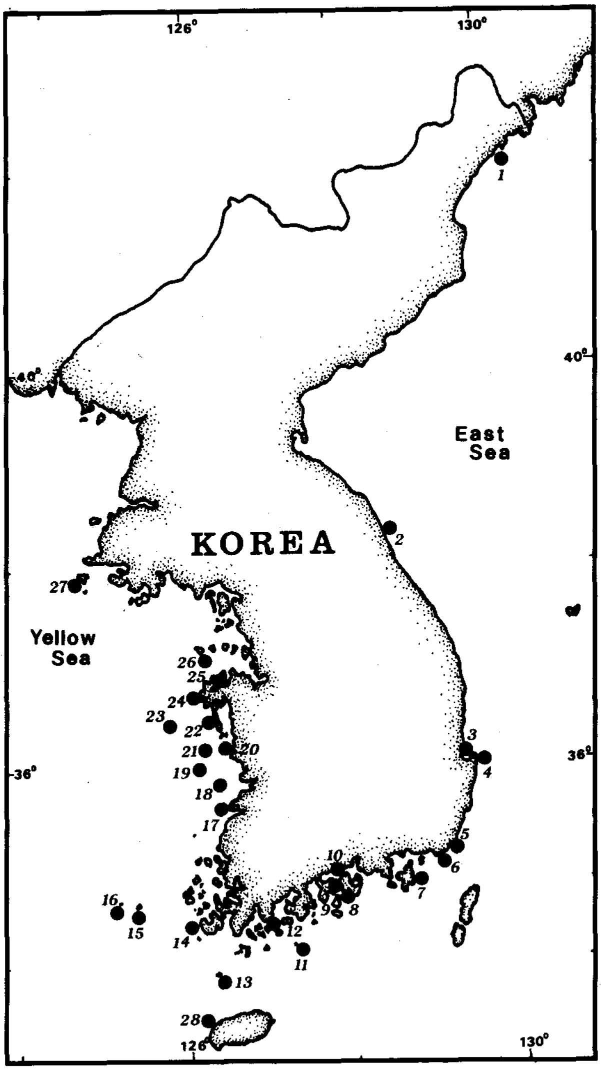

Fig. 1. A map showing the localities of *Chorda filum* in Korea. 1. Daechodo, Najin (Okamura 1917). 2. Ohori, Koseong-gun (Koh *et al.* 1989). 3. Pohang (Kang 1966). 4. Daebori, Youngil Bay (Lee and Oh 1986). 5. Dongbaekseom, Pusan (Lee and Kang 1971). 6. Pusan (Kang 1966). 7. Geojedo (Kang 1966). 8. Namhaedo (Kang 1966; this study). 9. Odongdo, Yeosu (Kang 1966). 10. Mibeob, Gwangyang Bay (Lee and Kim 1977; this study). 11. Dongdo, Geomundo (Lee and Boo 1984). 12. Maryangri, Gangjin-gun (Kang 1966). 13. Sinyang, Chujado (this study). 14. Guansado, Jindo-gun (Lee *et al.* 1983). 15. Seodumal, Daehugsando (Kang 1966; Lee *et al.* 1986). 16. Hongdo (Kang and Song 1984). 17. Chaeseokgang, Byeonsan Peninsula (Park and Kim 1990). 18. Bangchugdo, Jangjado, Biando and Munyeodo, Gogunsan Archipelago (Kang *et al.* 1981; Lee 1983). 19. Eocheongdo (Kang 1966; Kim 1978). 20. Muchangpo, Boryeong-gun (Yoo and Kim 1990). 21. Oeyeondo (Lee and Boo 1988; Cho and Boo 1996; this study). 22. Paeksajang, Taean Peninsula (Lee and Lee 1990). 23. Gyeokryeolbi Archipelago (Lee and Yoo 1978). 24. Oundol, Taean Peninsula (Lee and Lee 1990). 25. Yuldo, Garorim Bay (Lee and Lee 1982). 26. Pudo (Kang and Song 1984). 27. Dumujin, Baegryeongdo (Lee 1973; Lee *et al.* 1987). 28. Biyangdo, Cheju (Lee and Koh 1991).

from Chujado and Oeyeondo were taken from herbarium sheets and soaked in warm water with a few drops of detergent for five to six hours to examine anatomical characteristics. All the plants examined were deposited as herbarium sheets in the Herbarium of Cheju National University.

RESULTS AND DISCUSSION

Chorda filum **(Linnaeus) Stackhouse (1801, pp. xxiv, xxxv, 40)**

Basionym: *Fucus filum* Linnaeus (1753, p. 1162)

Synonyms: *Conferva filum* (L.) Lightfoot (1777, p. 963)

Scytosiphon filum (L.) J. Agardh (1848, p. 126)

Chorda filum (L.) Lamouroux (1812, p. 26), Okamura (1901, p. 55), Newton (1931, p. 200), Kang (1966, p. 48)

Korean name: 끈말

Plants gregarious on rocks and pebbles, cartilaginous with mucilaginous surfaces, pale brown, simple, chord-like, slightly tapering towards both ends, 3~4 mm broad at middle part, 100~160 cm long; holdfasts small discoid, composed of bundles of rhizoid, 2~3 mm in diam.; erect axes tube-like, with diaphragms at various intervals of internal lumen, with inner canal of ca. 2 mm in diam., composed of meristoderm, cortex and medulla arranged in lengthwise helical rows along growing axis; meristoderms composed of single-celled layer, 12~17 μm thick; meristodermal cells ellipsoid to oblong, longitudinally elongated, compacted with small granules, 5~12 μm broad, 12~20 μm long; cortices composed of 6~7 celled layer, 1,000~2,500 μm thick; cortical cells cylindrical in longitudinal view, polygonal in transverse view, 40~100 μm broad, 300~2,000 μm long; medullae constructed by reticular arrangement of long, hyaline hyphae; medullary cells long with inflated tips, fine with very thin walls, running longitudinally and transversely, immersed in transparent amorphous matrix, 8~24 μm broad, 60~140 μm long; diaphragms formed at various intervals, constructed with variously lobed medullary cells and transparent amorphous matrix, 6~10 μm thick; hairs developing from meristodermal cells, tufted, ca. 13 μm broad.

Sporangia born together with paraphyses on meristodermal cells, ellipsoid to fusiform, 5~10 μm broad, 35~50 μm long; paraphyses short, clavate, inflated at tips, 12~16 μm broad at inflated tips, ca. 4 μm broad at base, 60~80 μm long.

Distribution: Cold-temperate waters in the Northern

Hemisphere (Druehl 1981; Bold and Wynne 1985; van den Hoek *et al.* 1995).

Materials examined: LYP-1321 (Chujado 23 Aug. 1986, collected by Lee K.J.), LYP-1322 (Namhaedo 4 May 1997, collected by Oh Y.S.), LYP-1323 (Oeyeondo 21 Jul. 1992, collected by Lee Y.K.), LYP-1324 (Namhaedo 28 March 1998, collected by Oh Y.S.), LYP-1325 (Mibeob, Guangyang Bay 13 April 1998, collected by Oh Y.S.)

Habit and Morphology: Several individuals of *C. filum* grow gregariously on rocks, shells or pebbles in the shallow subtidal zone at the much sheltered area (see also Okamura 1901). Plants take a long thread form gradually tapering toward both ends and occasionally intertwisted at the lowermost part of plants (Fig. 2A). The plants from Oeyeondo in July and Namhaedo in May are usually longer than 100 cm. Lee *et al.* (1987) reported the plants more than 600 cm long and forming a wide mat under water of 10 m depth in July. The hold-plant take a somewhat rigid and massive discoid form constructed by the tightly entangled rhizoids that develop from the meristodermal cells of the lowermost part of plant (Figs 2C, 3G, H). The rhizoids are uniseriate filamentous, contorted, rather rigid, occasionally giving rise to branches, with obtuse ends or palm-like forms at the end, and 10~20 μm thick.

Vegetative structure: The proximal end of plant is turbinate and stuck in the massive disc of holdfast. The cortical cells in the proximal end are comparatively shorter and containing granules more compactly than those in the middle to upper part (Figs 3H, 4G). The internal lumen and the medullary hyphae also appear to the proximal end (Fig. 3H). Consequently, most cortical cells seem to be formed newly at the proximal end of plant. The outermost cortical cells may not be derived from meristodermal cells in the point that the former has numerous pits with the adjacent cortical cells. Hyphae in medullary layer are also formed at the extremity of the base and also derived from innermost cortical cells above the base. Kogame and Kawai (1996) demonstrated that the sporophyte of *C. filum* had three developmental growth stages, when young. However, such meristem was not found on the mature plant examined.

All of the component tissues of plant are arranged in lengthwise helical rows along the axis. A few grooves running coincidently with the helical rows of the tissues occur on the surface of full grown plant (Fig. 2B). Thus, plants appear to be a rather twisted thread-form.

Meristodermal cells are hardly recognized in surface view because those in almost whole parts of plant give rise to sporangia and/or paraphyses when mature (Figs 3B, C). However, the meristodermal cells issuing hairs keep retaining the stubs of the hair between paraphyses or sporangia (Fig. 3D). When young, long hairs cover the whole surface to make the surface of the plant much lubricous (Okamura 1901; Newton 1931).

Cortical cells are long, cylindrical with truncate ends and appearing to be transparent as they contain a small amount of granules only at the corner of either end. The outermost cells of cortex are similar in shape and size to meristodermal cells in transverse view (Fig. 3A). Okamura (1901) described the meristoderm (epidermis *sensu* Okamura) of the plant as "a few layers of epidermal cells." However, the outermost cells of cortex show a long cylindrical form in longitudinal view, while the meristodermal cells are ellipsoid to oblong and slightly elongating outwards (Fig. 4A). Cortical cells generally have much thick side walls that are 10~15 μm thick and resulting in a rather tough texture and tension, while the cross walls at the both ends are comparatively thin (Figs 3A, E, F).

Delicate cytoplasmic connections traverse through numerous pits. The pits occur in roughly longitudinal rows on the side wall and in even dispersion on the cross wall (Figs 3F, 4A-D, G). The pits and the sieve-tubes have been generally known to occur in the trumpet-hyphae of the plants of Laminariales (cf. Oltmanns 1922, pp. 160-163; Fritsch 1945, pp. 229-235). The pits on the side wall of cortical cell has been already illustrated in the figures of Reinke (1892 Taf. 26 Figs 6, 10; Taf. 27 Figs 4, 6, 8). However, no discription on the pits of cortical cell wall was given by him.

The medulla of this species is rather poor and composed of a reticulum of trumpet hyphae with a thin and smooth wall (Figs 3E, 5A, B). The hyphae generally show a long and hyaline tube-form with abruptly inflated ends and have a thin and smooth wall. Such form of the hypha with inflated ends, trumpet-hypha, is common in the plants of Laminariales (Fritsch 1945, p. 231). The hyphae are usually immersed in an amorphous transparent matrix (Figs 3E, 5B). Occasionally, a part of hypha is emersed from the amorphous transparent matrix into the internal lumen as a free hypha. The hyphae immersed in matrix issue a bundle of branch toward the internal lumen. The branches are composed of various cells such as rod-shaped, discoid, and with various lobes, which are distinguished in cell shape from the medullary hyphae (Fig. 5D). The branches are interwoven rather loosely and also immersed in the amorphous

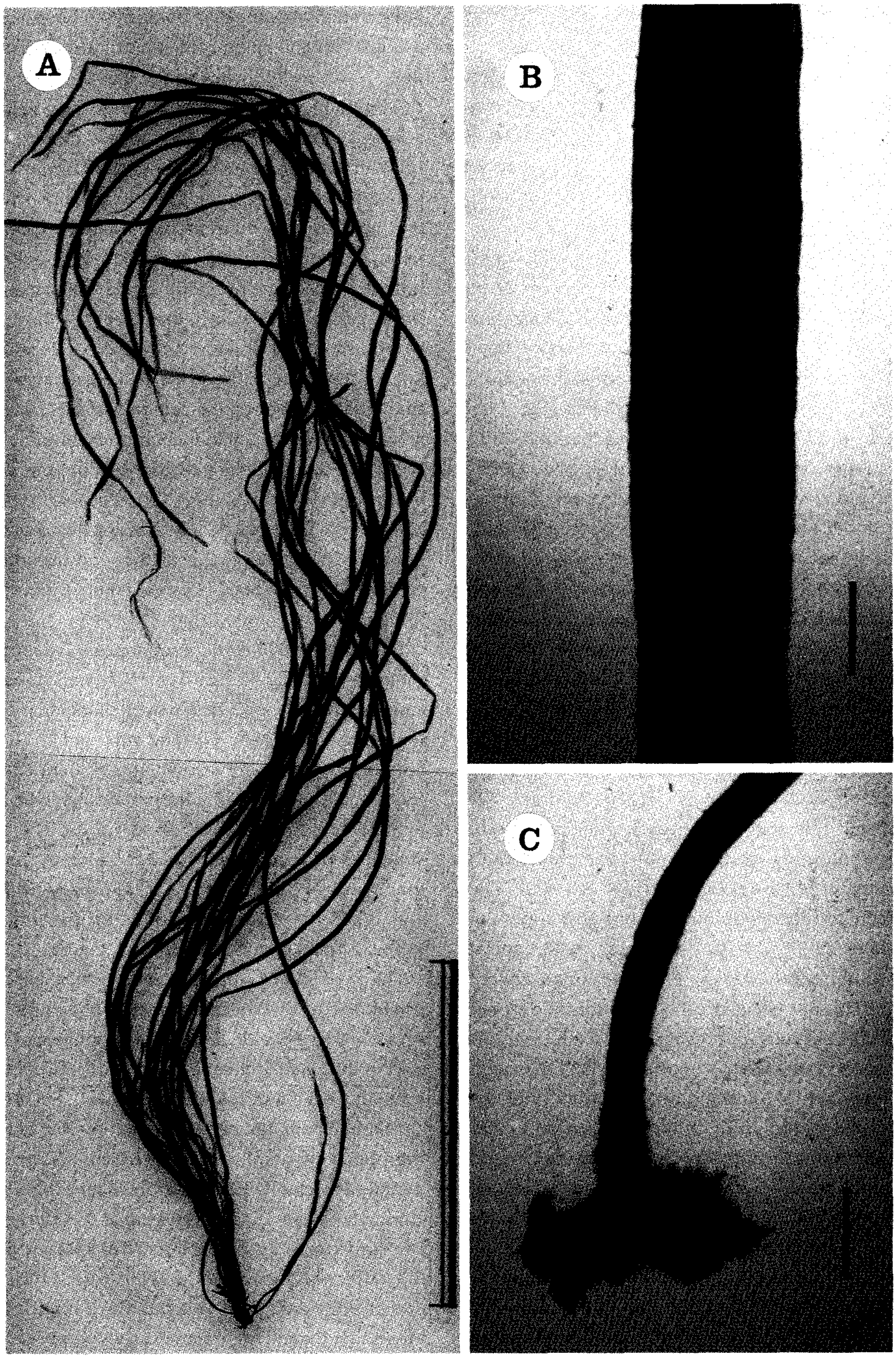

Fig. 2. *Chorda filum* (L.) Stackhouse. A. Habit of mature plants. B. Middle part of frond, showing the surface with grooves running up twistedly. C. Holdfast. Scale bars; A = 20 cm, B = 1 mm, C = 2 mm.

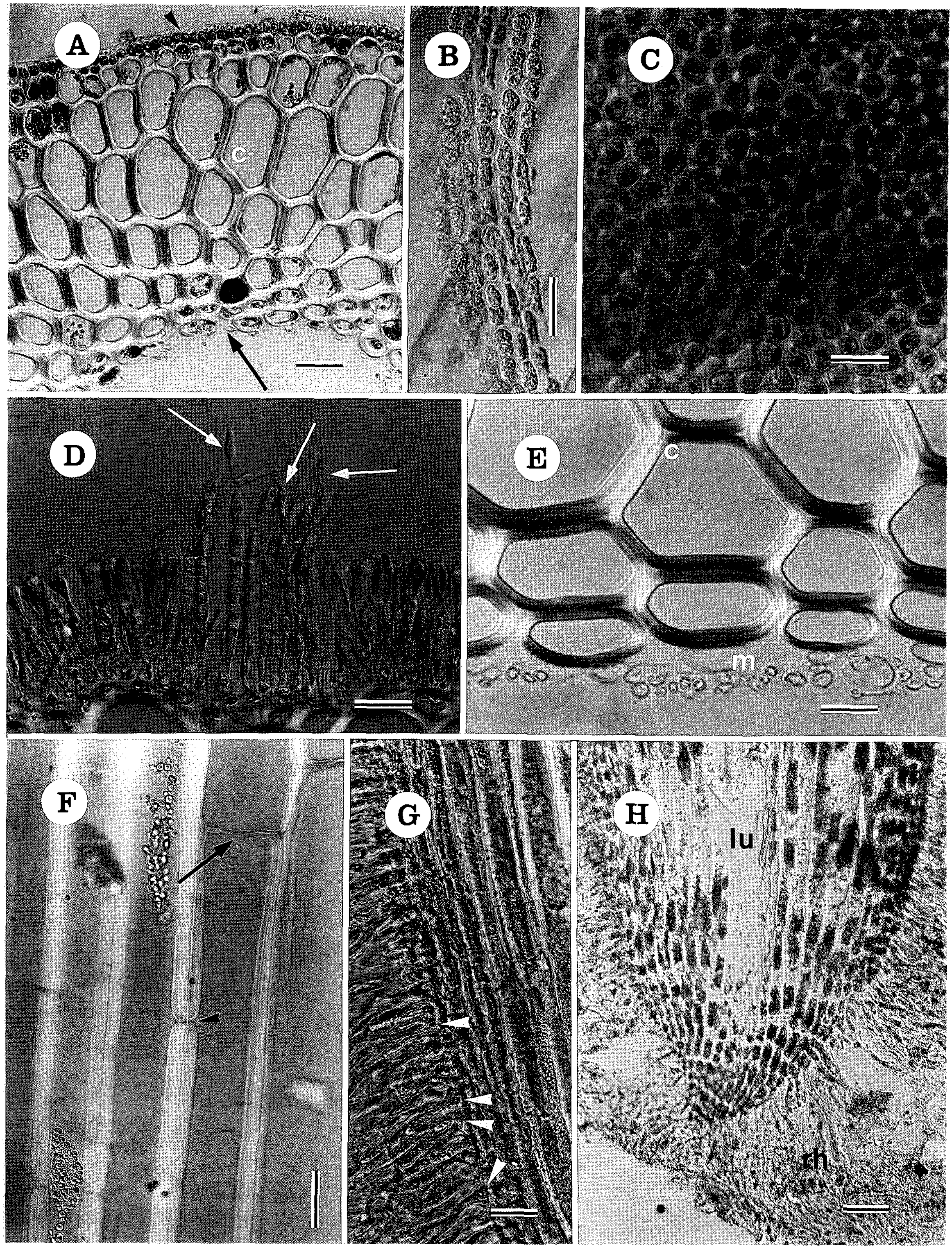

Fig. 3. *Chorda filum* (L.) Stackhouse. A. Transverse section of the lower part of plant showing the meristoderm (arrow head), cortex (c), and medulla (arrow). B. Surface view of meristodermal cells. C. Surface view of the fertile part showing the outer end of paraphyses. D. Transverse section of the fertile part bearing hairs (arrows). E. Transverse view of cortical cells (c) with thick wall and medullary cells (m) with thin wall. F. Longitudinal section of cortex showing cylindrical cells with truncate cross wall (arrow) and a pit (arrow head) on thick side wall. G. Longitudinal section of the base of plant showing the rhizoids arising from meristodermal cells (arrow heads). H. Longitudinal section of the proximal end of plant showing the acute end with lumen (lu) and rhizoids (rh). Scale bars; A,G = 50 μm, B-F = 30 μm, H = 100 μm.

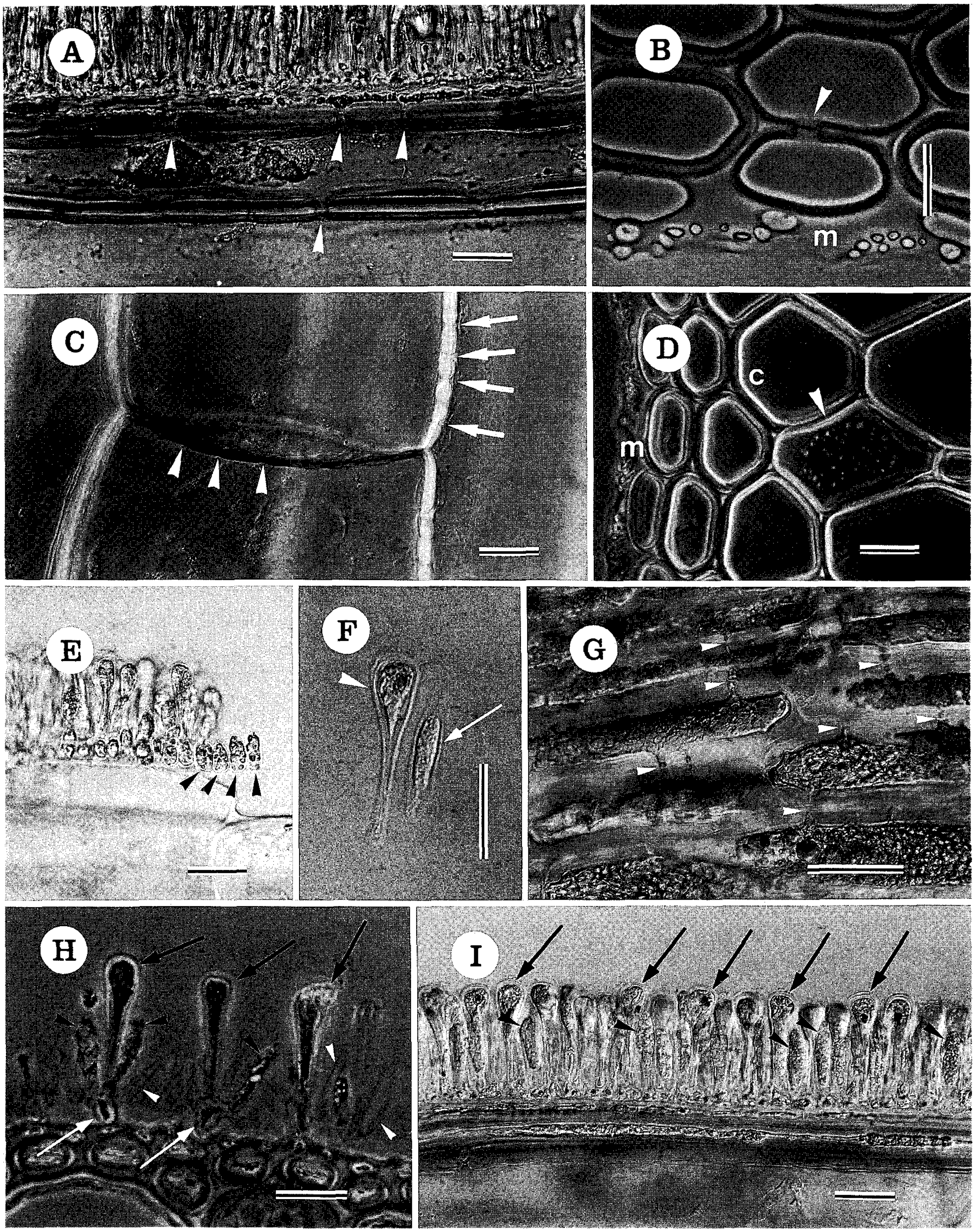

Fig. 4. *Chorda filum* (L.) Stackhouse. A. Longitudinal section of the outer cortical cells having numerous pits (arrow heads) on the side wall. B. Transverse section of the inner part of cortex and the medulla (m) showing a pit (arrow head) on the side wall of cortical cell. C. Longitudinal section of cortical cell having numerous pits on the cross wall (arrow heads) and the side wall (arrows). D. Transverse section of cortex (c) and medulla (m) showing numerous pits on the cross wall (arrow head) of a cortical cell. E. Meristodermal cells (arrow heads) elongating to issue a sporangium or a paraphysis. F. Paraphysis (arrow head) and sporangium (arrow). G. Longitudinal section of cortex in the lower part of plant showing numerous pits (arrow heads). H. Transverse section of old part showing meristodermal cells (white arrows) bearing paraphyses (black arrows) and sporangia (black arrow heads) as well as empty sporangia (white arrow heads). I. Side view of the arrangement of paraphyses (arrows) and sporangia (arrow heads). Scale bars; A-C, E, F, H, I = 30 μm, D, G = 50 μm.

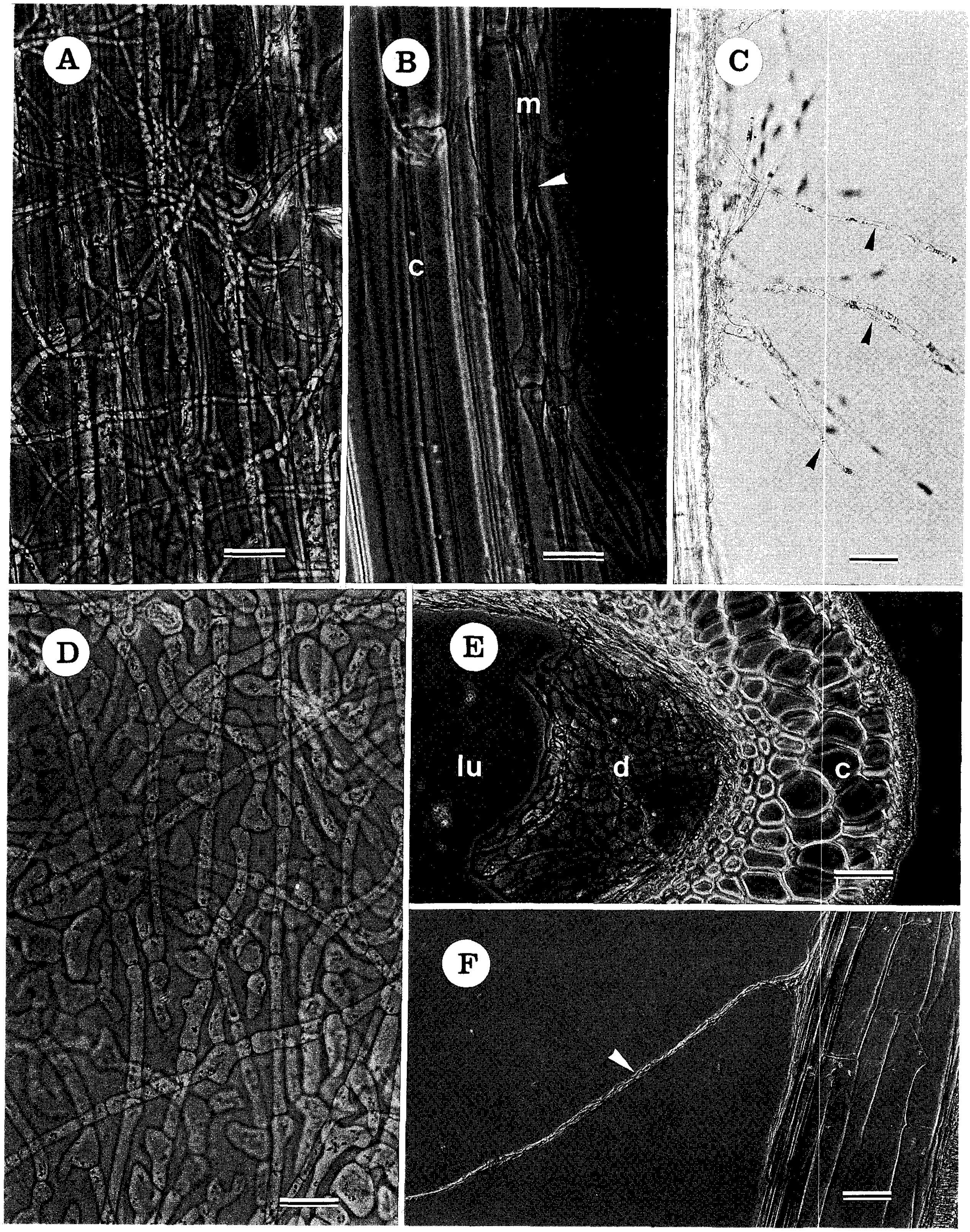

Fig. 5. *Chorda filum* (L.) Stackhouse. A. Inner surface view of medulla showing a reticulum of hyphae. B. Side view of the inner part of plant showing cortex (c) and trumpet-hyphae (arrow head) of medulla (m). C. Rhizoid like filaments (arrow heads) developing on the internal lumen. D. Surface view of diaphragm. E. Transverse section of the part with a diaphragm (d). c: cortex, lu: lumen. F. Longitudinal section of plant showing the transverse view of diaphragm (arrow head). Scale bars; A,B,D = 50 μm. C,E,F = 100 μm.

and somewhat cartilaginous matrix forming a lamina "diaphragm" (Figs 5D-F). The diaphragm traverses the internal columnar lumen of frond at various intervals. Some hyphae in a certain part, which seemed to be wound and contacted with outer environment, develop into a free filament (Fig. 5C). The filaments seem to be a sort of rhizoids because they are uniseriate and somewhat contorted with a rough surface. The internal lumen occupies 50~60% of the diameter of plant

Reproductive structures: All of the plants examined are fully matured and bearing sporangia along the whole surface of plant except near the holdfast. On the development of sporangium and paraphysis, the meristodermal cells elongate outwardly and divide into two compartments (Fig. 4E). The outer one of the daughter cells develops into either a paraphysis or a sporangium, while the inner one appears as a stalk cell (Fig. 4I). However, the stalk cells, even of the paraphysis, issue new sporangia successively (Fig. 4H). Paraphyses are short clavate with a rather rapidly inflated tip and narrow base (Figs 4F, H, I). Sporangia are longish ellipsoid to clavate although they are shorter than paraphyses (Figs 4F, H, I). Consequently, the sporangia are arranged together with paraphyses rather tightly forming an outermost palisade layer of plant body, although only the swollen tips of paraphyses are shown in surface view (Figs 3C, 4I).

Distribution: The plants of *C. filum* occur in the subtidal zone as well as rock pools of sheltered and calm places along the coasts of Korea (Fig. 1). The first record of this species in Korea was made by Okamura (1917) from Daechodo, Najin Bay, in the northernmost region of the eastern coast. *C. filum* was also found from May to October at Ohori in the middle region (Koh *et al.* 1989) and occasionally at Pohang and Daebori, Youngil Bay, in the southernmost region of the eastern coast (Kang 1966; Lee and Oh 1986). The southern coast may be a good habitat for this species owing to the various coastal embayment. This species was frequently found at Haeundae and Pusan in the easternmost region, Geojedo, Namhaedo, Gwangyang Bay and Odongdo in the middle region, and Maryangri, Jindo and Huksando in the westernmost region of the southern coast of Korea, respectively (Kang 1966; Lee and Kang 1971; Lee and Kim 1977; Lee *et al.* 1983). Lee (1973) reported 2 m long and mature plants growing on rocks covered with sand in the intertidal zone of Baekryeongdo in the middle region of the western coast of Korea in July. And also Lee *et al.* (1987) reported a large population with 6 m long plants in the 10 m deep rocky bottom at Dumujin of Baegryeongdo in July. Consequently, this suggests that the habitat of Dumujin is the best for the plants to grow up along the coasts of Korea. The plants also occur along the whole western coast of Korea (see also Lee 1991; Kim 1994). The plants of *C. filum* grows usually on deep bottoms in the northern region, while those occur in shallow water or rock pools in the southern region (Lee and Oh 1986; Lee *et al.* 1987). Geomundo and Chujado may be the southern limits of the distribution of *C. filum* in Korean waters (Lee and Boo 1984). However, the occurrence of this species was reported by Lee and Koh (1991) from the 15 m deep bottom with *Laminaria* beds at Biyangdo, Cheju Island. It is directing our attention to the geographic distribution of this species because *C. filum* had not been found by several floristic and ecological surveys for Cheju Island (Kang 1960; Lee 1976; Lee and Lee 1976, 1982; Yoon 1985).

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