J. Plant Biol. 39(1) : 23-29 (1996)

Morphology and Reproduction of *Polysiphonia atlantica* Kapraun et J. Norris (Rhodomelaceae, Rhodophyta)

Kim, Myung-Sook and In Kyu Lee*

Department of Biology, Seoul National University, Seoul 151-742, Korea

Morphology and reproduction of *Polysiphonia atlantica* Kapraun et J. Norris were studied on the basis of field and laboratory cultured materials collected from the coast of Korea. The plants consisted of prostrate and erect axes with an extremely soft flaccid texture. Axes were ecorticated and had four pericentral cells. The plants except for female gametophytes had few trichoblasts. Branches in the upper portion of the thallus grew to the same level, resulting in a flat-top form. Tetrasporangia were arranged in straight series. Spermatangial branches replaced whole trichoblasts and had a 1-2 celled sterile tip. The procarp had a four celled carpogonial branch. After fertilization, the carpogonium contacted the surface of the supporting cell. The formation of the auxiliary cell from the supporting cell was somewhat delayed. *P. atlantica* from Korea was similar to *P. subtilissima* Montagne in some features. However, the taxonomic differences between the two species were identified in the development of branches and the number of sterile cells at the tip of spermatangial branches.

Keywords: laboratory culture, morphology, *Polysiphonia atlantica*, reproduction, Rhodophyta, taxonomy

The morphology of the female reproductive structure in the genus *Polysiphonia* has been previously investigated only in a few species by Fritsch (1945), Kylin (1956), and Hommersand and Fredericq (1990). However, their results differed among species, so that no definite opinion could be induced in the reproductive development of the genus.

In the present study, we studied the behavior of the carpogonium and the formation of the auxiliary cell in *Polysiphonia atlantica* Kapraun et J. Norris (1982). Our observations were compared with those of previous researchers regarding the fusion of the fertilized carpogonium and the time of the auxiliary cell formation.

P. atlantica is one of the common species in the Atlantic and Indian Oceans (Maggs and Hommersand, 1993). This alga is characterized principally by having four pericentral cells, rhizoids in open connection with pericentral cells, rare or absent trichoblasts, and spermatangial branches replacing the whole trichoblast. In studying the Korean species of *Polysiphonia*, we found these taxonomic characteristics occurred commonly among several species such as *P. urceolata* (Dillwyn) Greville (1824), *P. subtilissima* Montagne (1840), *P. abscissa* Hooker et Harvey (1845), *P. morrowii* Harvey (1856), *P. pacifica* Hollenberg (1942), and *P. pungens* Hollenberg (1942). Therefore, a comparative study for the delimitation of the species is needed to evaluate the stability of each taxonomic feature.

In this paper the morphological and reproductive characteristics and the life history in laboratory culture as well were reinvestigated with *P. atlantica* based on materials collected from the Korean coasts.

MATERIALS AND METHODS

Materials were collected from the coasts of Korea during 1991 and 1994. Plants were examined in fresh or preserved state in 4% formalin seawater. Materials for culture were obtained in January, 1991 from Daesambudo (34°03′ N, 127°23′ E), in the southern coast of Korea. Unialgal culture was examined according to the method of Boo and Lee (1983). Cultures were kept at 15 °C under white fluorescent light at 30 $\mu mol \cdot m^{-2} \cdot sec^{-1}$ and 12 : 12 LD.

*Corresponding author: Fax +82-2-872-6481

Description and illustrations were carried out under light microscope. For anatomical investigation the materials were cleared with 5~10% NaOH in distilled water for 2~7 days, and rinsed with distilled water. All drawings were made using a camera lucida on a Olympus microscope. Specimens examined were deposited at the Herbarium, Seoul National University (SNU).

RESULTS

Vegetative structures

Thalli are 0.5~1.5 cm high, dull red to brownish-red in color with an extremely soft flaccid texture (Fig. 1A). They consist of prostrate and erect axes, and branch in 4 orders (Fig. 1D). Axes are ecorticated with one slender central cell and 4 pericentral cells (Fig. 1E). Prostrate axes are curved downwards at the tip, providing a large conspicuous apical cell divided transversely. The first-formed pericentral cell is placed in ventral position (Fig. 1B, C). Branches are endogenous near the apex, and 50~100 μm in diameter when fully grown. Rhizoids are formed medially from the pericentral cells and remain in open connection with the cell (Fig. 1F). They are 30~50 μm in diameter and up to 1 mm long.

Erect axes are curved adaxially when young, and become straight in adult. Primary laterals are endogenous, emerging adaxially near the apex. Adventitious laterals originate at a distance from the apex and endogenously. They never arise from scar cells or pericentral cells. Exogenous branches and trichoblasts are occasional to common in female plants, but rare or absent in male plants, tetrasporic and vegetative plants. Plastids are angular plate or beaded forms.

Reproductive structures

Spermatangia are developed on a monosiphonous determinate branchlet derived from the central cell. In a fertile axis, every segment at the distal end produces a spermatangial branchlet. Thus, the arrangement of branchlets shifts from alternate-distichous to a spiral arrangement. The spermatangial branchlets are polysiphonous, except for two proximal and two to three distal segments. The basal segment is always embedded in the central frond, whereas the suprabasal segment protrudes freely. Each segment of spermatangial branchlet produces four pericentral cells. All the terminal cells derived from the pericentral cell, including pericentral cell itself, become spermatangial mother cells. They produce two to three spermatangia respectively. A mature spermatangial branchlet is a slightly incurved cone-shape. They terminate in a single or two continuous sterile cells and become 290~340 μm long and 45~60 μm wide. Trichoblasts are not seen in the male gametophyte (Fig. 1G).

Procarp formation is initiated on the second segment, a suprabasal cell of the trichoblast near the apical cell (Fig. 2A). The cell cuts off five pericentral cells in an alternate manner (Fig. 2B). The fifth pericentral cell produced lastly always becomes fertile, and acts as a supporting cell. This supporting cell first cuts off the initial of the first sterile group (lateral sterile group) on the lateral side, then the initial of the carpogonial branch, and lastly the second sterile group (basal sterile group) initial below the initial of carpogonial branch (Fig. 2C, D). The carpogonial branch becomes four-celled: the first, derived from the supporting cell, is relatively large, and the fourth gives rise to a long upwards trichogyne (Fig. 2E, F). After fertilization the trichogyne is cut off, the carpogonium broadens to touch and adheres to the surface of the supporting cell (Fig. 2G-I). The auxiliary cell is cut off from the upper portion of the supporting cell after a presumed transfer of the zygote nucleus. The two sterile groups divide once, so that the first sterile group becomes four-celled and the second group two-celled (Fig. 2J). The gonimoblast initial is cut off from the distal end of the auxiliary cell which is gradually enlarged, and forms a single compacted gonimolobe. Sympodial divisions are seen in the early stage of cystocarp formation. The terminal or subterminal cells of the gonimolobe are subsequently transformed into carposporangia. The fusion between the auxiliary cell and the supporting cell is extended to the neighboring axial cell of the fertile segment and the lower cells of the gonimolobe, so that a large fusion cell is formed at the base of the cystocarp (Fig. 2K). A mature cystocarp is urceolate, and about 400~450 μm long and 300~400 μm wide (Fig. 1H).

Tetrasporangium formation is always restricted to the second or third pericentral cells. Tetrasporangia are produced from the pericentral cell of a stichidium. The fertile pericentral cell first cuts off two cover cells at its upper end, and then the tetrasporangial initial from the abaxial side to the central axis of the stichidium. Mature tetrasporangia are divided tetrahedrally and are 100~110 μm in diameter. They

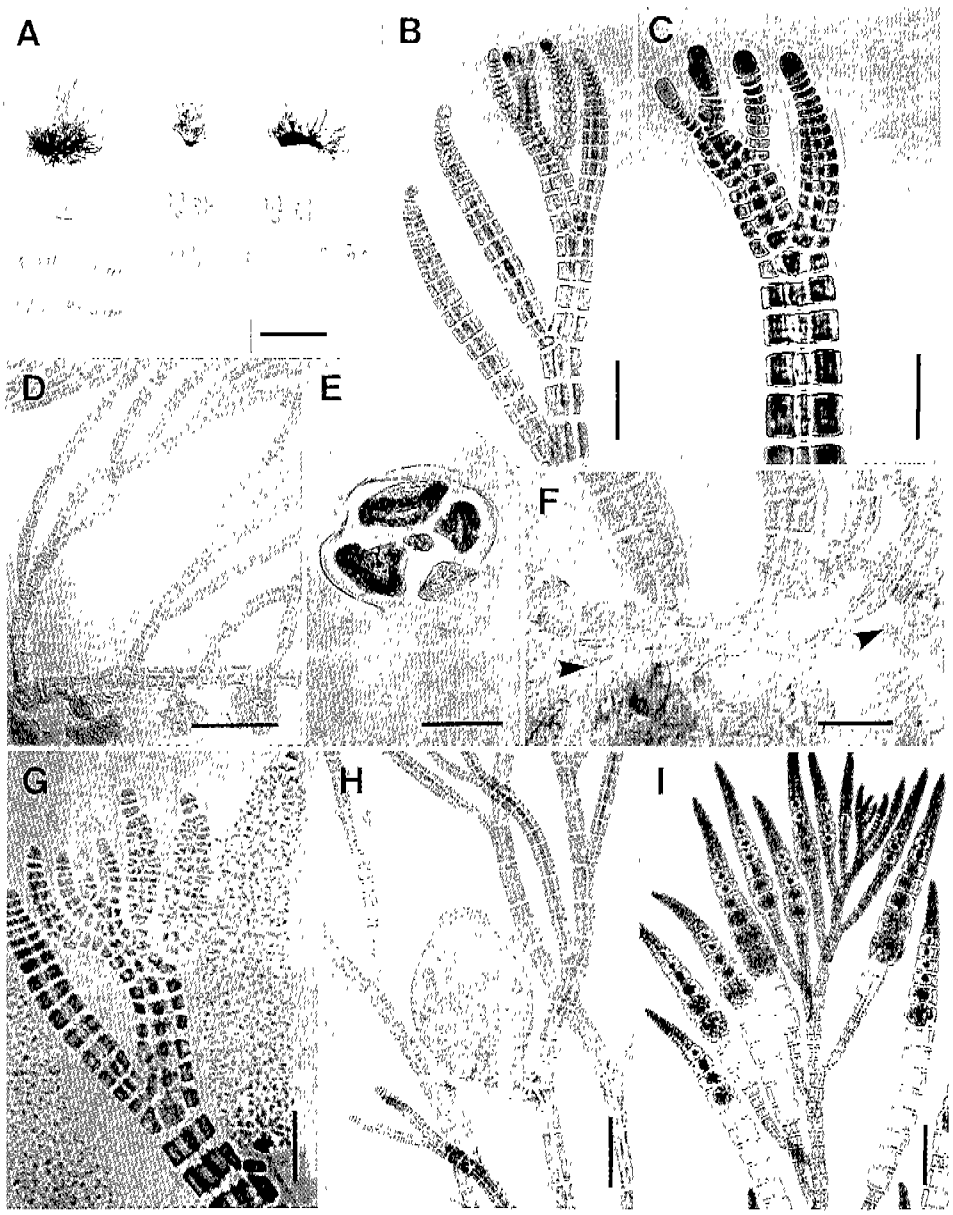

Fig. 1. *Polysiphonia atlantica* Kapraun et J. Norris. A, Herbarium specimens collected in Daesambudo; B-C, Apices growing from large domed apical cells; D, Prostrate and erect axes; E, Four pericentral cells without cortication; F, Rhizoids without septation (arrowhead); G, Replacing the whole trichoblast of the spermatangial branches; H, A urceolate shape of a mature cystocarp; I, Straight series of tetrasporangia (scale bars; A=1 cm, B=100 μm, C=60 μm, D=250 μm, E, G=50 μm, F=70 μm, H, I=200 μm).

are arranged in straight series (Fig. 1I).

Laboratory culture

Unialgal cultures were obtained from the tetraspores isolated. Released tetraspores were spherical and 30~40 μm in diameter (Fig. 3A). Attached spores began to germinate in five hours (Fig. 3B). They elongated until the first division occurred to form two unequal cells (Fig. 3C). After three days, the germling became filamentous with seven to eight cells and a rhizoid (Fig. 3D-G). The early germling showed a distal erect type. Spermatia were produced after five weeks, and procarpic structures after six weeks. They fertilized successfully, and matured into cystocarps in three weeks (Fig. 3H). The

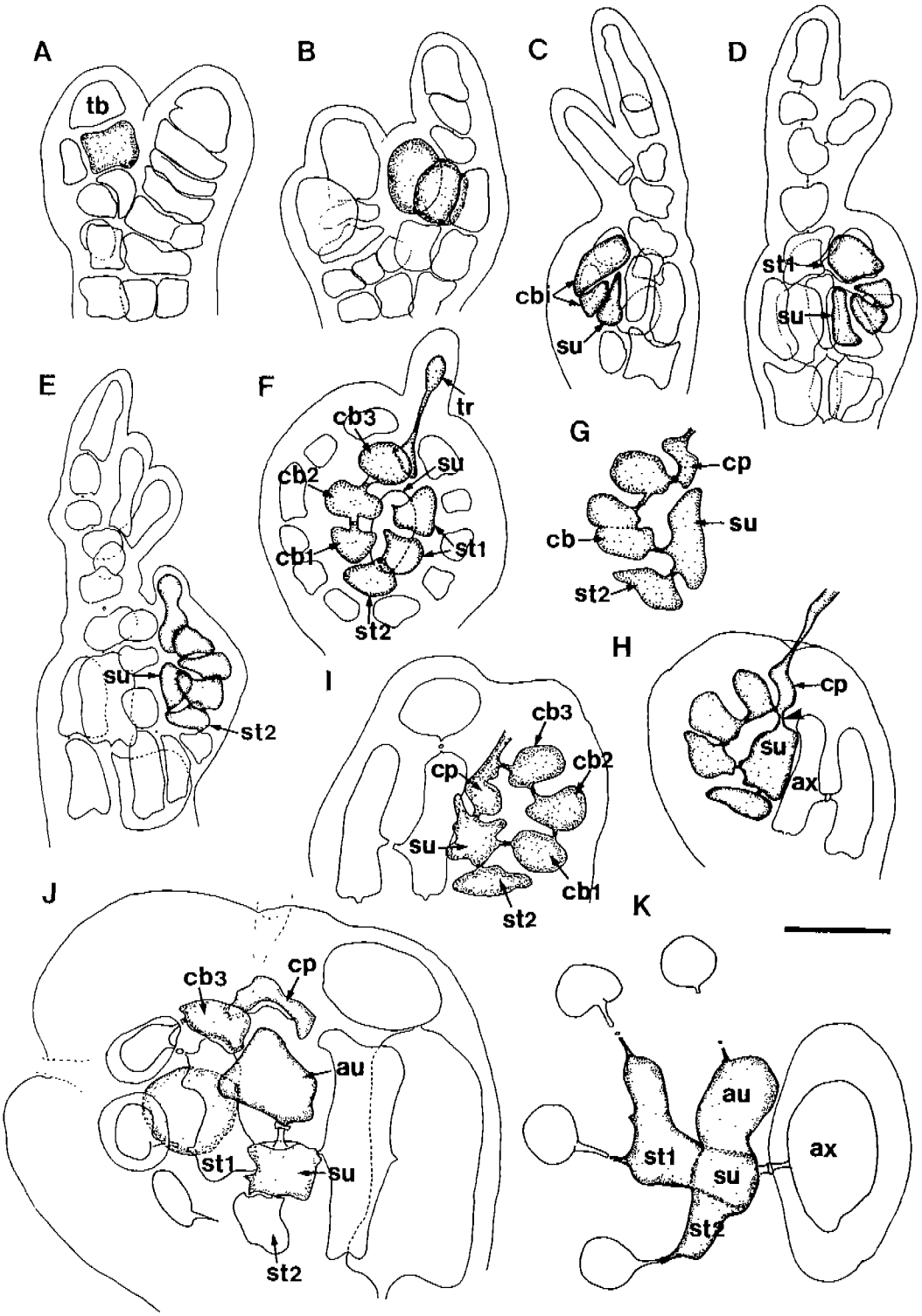

Fig. 2. *Polysiphonia atlantica* Kapraun et J. Norris. A-B, Development of procarp; C-F, Formation of four-celled carpogonial branch and sterile cell; G-I, After fertilization, carpogonium contacting the surface of the supporting cell; J, Auxiliary cell cutting off from the distal end of the supporting cell; K, Incorporation of supporting, sterile, and auxiliary cells to the fusion product (au=auxiliary cell, ax=axial cell, cb=carpogonial branch, cbi=carpogonial branch initial, cp=carpogonium, st=sterile cell, su=supporting cell, tb=trichoblast cell, tr=trichogyne, scale bar=30 μm).

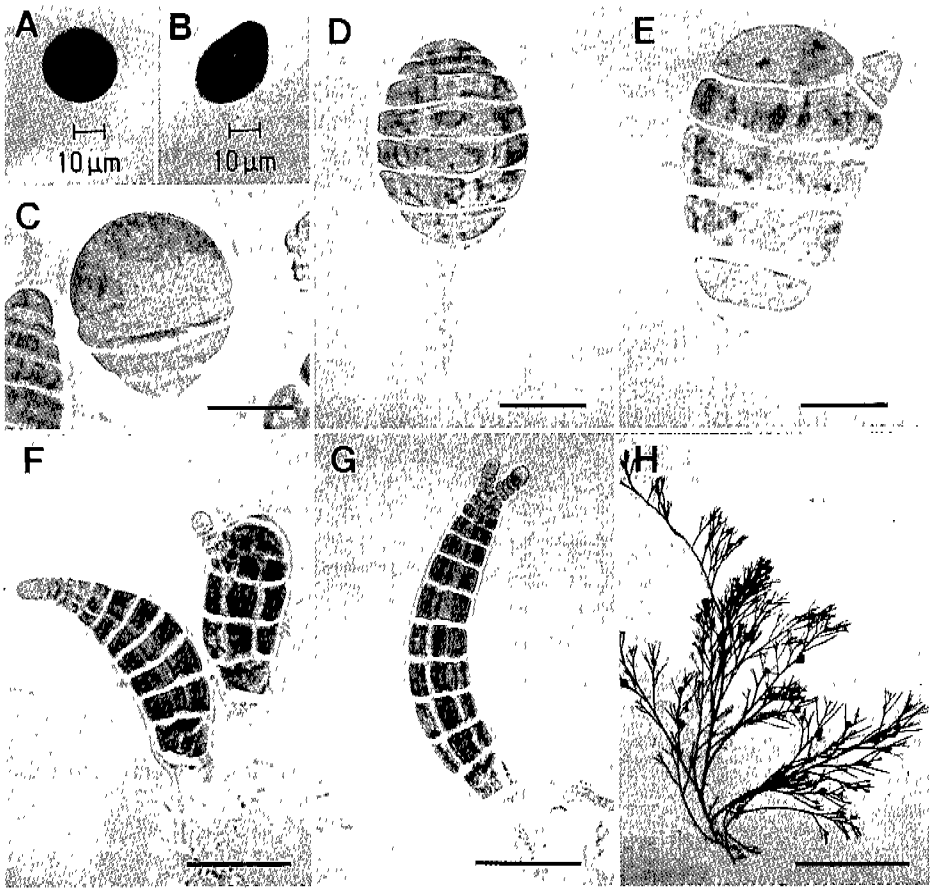

Fig. 3. *Polysiphonia atlantica* Kapraun et J. Norris. A, Released tetraspore; B-C, Germination of tetraspore; D-G, Typical distal erect sporeling and initiation of first lateral branch; H, Female plant with cystocarps in culture (scale bars; C, D=25 μm, E=20 μm, F, G=15 μm, H=0.5 cm).

released carpospores developed into tetrasporophytes in eight weeks after germination. As a result, *P. atlantica* required about three to four months to complete a life history in laboratory culture. The trichoblasts were not observed on the male, tetrasporic and vegetative thallus of these cultured plants.

DISCUSSION

Species of *Polysiphonia* have been identified by major distinguishable characteristics such as: 1) the number of pericentral cells, 2) the existence of cortical cells, and 3) whether the rhizoids are connected to the pericentral cells or not (Hollenberg, 1968; Womersley, 1979). According to our study, the existence of prostrate branches can be added as one more important characteristic, because the plants are usually composed of the erect branches or the prostrate and erect branches. In laboratory culture, the plants did not produce vegetative trichoblasts as in the field. Thus, we consider the absence or rarity of trichoblasts of this species as a stable diagnostic characteristic, although it may be a characteristic of local populations as well. *P. atlantica* also has the feature in which alternate branches arise two by two at the upper part, and has determinate branches, like *P. morrowii*. *P. morrowii*, however, is characterized by an acute tip of apical cells, in contrast to *P. atlantica*, which has dome-shaped apical cells in the determinate branches.

The position of spermatangial branches provides a major identification basis for the species of *Polysiphonia* (Hollenberg, 1942; Maggs and Hommersand, 1993). Spermatangial branches of *P. atlantica* are replaced by the whole trichoblast bearing a sterile tip of 1-2 cells. In this replacement, *P. atlantica* may resemble *P. morrowii*. However, the morphological characteristics of the spermatangial branches differ; *P. atlantica* has a 1-2 celled sterile tip, while *P. morrowii* has a 5-8 celled one (Kim *et*

al., 1994).

Procarp formation of *Polysiphonia* is essentially the same as that in the other genera of the Rhodomelaceae (Hommersand, 1963; Masuda, 1982). However, detailed examinations on the post-fertilization process somewhat differ among investigators (Kylin, 1923; Broadwater and Scott, 1982; Hommersand and Fredericq, 1990). Kylin (1923) reported that in *P. nigrescen*, the supporting cell produced the auxiliary cell simultaneously with fertilization. Broadwater and Scott (1982) suggested that in *P. harveyi* a hormone was released from the fertilized carpogonium, and transported through the carpogonial branch to the supporting cell, where it triggered the formation of the auxiliary cell. Hommersand and Fredericq (1990) described that in *P. harveyi* two connecting cells were formed from the carpogonium, and the auxiliary cell expanded and fused with the connecting cell, and a derivative of the fertilized nucleus was transferred to the auxiliary cell either by a carpogonial process through direct fusion or the transfer was mediated by a connecting cell. In the Korean *Polysiphonia* plants, however, we could observe no definite connecting cell. In *P. atlantica* the connecting cell was also not observed, and the formation of the auxiliary cell seemed to be delayed as in *Laurencia similis* (Nam and Saito, 1991).

Womersley (1979) mentioned that *P. subtilissima* Mantagne, *P. abscissa* Hooker et Harvey (1845), and *P. pacifica* Hollenberg (1942) are a complex of closely related taxa and may prove to comprise only one species. He suggested that *P. atlantica* (as *P. macrocarpa*) and *P. subtilissima* Montagne were closely related by the rhizoids in open connection with pericentral cells, branches replacing trichoblasts, and the spermatangial branches replacing the whole trichoblast. However, he mentioned that *P. atlantica* differed in habit by forming lower more spreading mats or tufts, in contrast to the erect fastigiate tufts and flat-topped branch system at the apex of *P. subtilissima*. In our study, *P. atlantica* is distinguished by having a 1-2 sterile apical cells on the spermatangial branches, while *P. subtilissima* has 4-6 celled sterile tip (Womersley, 1979).

Kapraun (1977, 1979) and Kapraun *et al.* (1983) added taxonomic characteristics of these taxa in the western Atlantic, mentioning that *P. atlantica* gave rise to unilateral filaments from prostrate axes, producing a dorsiventral habit, while *P. subtilissima* had a radial development of branches in the prostrate axes.

The Korean plants of *P. atlantica* have long been known to be somewhat similar to *P. subtilissima* (Yoon, 1986). According to our investigation, however, they are well identified as *P. atlantica* by the following unique characteristics: 1) an extremely soft and flaccid texture, 2) a well developed prostrate system, 3) small height, 4) an urceolate cystocarp, 5) 1-2 sterile cells at the spermatangial branch tip, and 6) a habitat of normal salinity sea water.

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(Received February 10, 1996)

紅藻 *Polysiphonia atlantica* Kapraun et J. Norris의 形態와 生殖

金 明 淑 · 李 仁 圭*
서울大學校 自然科學大學 生物學科

적 요

홍조 애기붉은실(신칭: *Polysiphonia atlantica* Kapraun et J. Norris)의 형태 및 생식 기관의 해부학적 특징을 야외와 실내배양 재료를 통하여 검토하고, 그 생활사를 밝혔다. 본 종은 형태적으로 포복지와 직립지로 구성되며, 피층세포가 없는 4개의 주심관을 가지고, 가근은 주심세포와 연결되며, 모상엽은 영양체, 사분포자체, 수배우체에서 없거나 드물고, 정단부 가지의 길이가 모두 비슷해서 flat-topped level을 형성하는 특징을 보여주었다. 사분포자는 일렬로 배열하며, 정자낭지는 모상엽 전체와 대치되고 정단부에 1~2개의 불염세포를 가진다. 전과체는 4개의 태원열로 이루어지고 수정된 후 조과기는 지지세포와 부착하며, 조세포의 발달이 다소 지연되는 점이 특이하였다. 한편, 애기붉은실은 각시붉은실(*P. subtilissima* Montagne)과 몇 가지 특징들에 있어서 서로 유사하므로, 그들의 형태적 차이점과 분류학적 유연관계에 대하여 논의하였다.

주요어: 애기붉은실(국명신칭), 형태, 생식, 실내배양, 분류, 홍조

*교신저자: Fax (02) 872-6481