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Life History of *Porphyra seriata* Kjellman (Bangiales, Rhodophyta) from Korea in Laboratory Culture

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The laboratory culture study of *Porphyra seriata* Kjellman from Korea was conducted at different conditions of temperatures (5, 10, 15, 20, 25 and 30°C), photon flux densities (10, 20, 40 and 80 μmol m^{-2} s^{-1}) and photoperiods (14L: 10D and 10L:14D). Conchocelis filaments grew fast at 15-20°C and 20-80 μmol m^{-2} s^{-1} under both photoperiods. Conchosporangial branches were produced at 5-25°C, and abundant when the conchocelis filaments were cultured at higher temperatures of 20-25°C under both photoperiods. Foliose thalli grew well at 15-20°C under 10L:14D and at 20°C under 14L:10D. At 30°C, the foliose thallus failed to survive. No archeospores were observed at any culture conditions. Spermatangia and zygotosporangia were formed in squarish patches at the upper marginal portion of mature thalli. Anatomical examination revealed that the mature spermatangia were 64 (a/4, b/2, c/8) and 128 (a/4, b/4, c/8), and that of zygotosporangium was 16 (a/2, b/2, c/4) according to the Hus' formula.

Key Words: Bangiales, culture, life history, *Porphyra seriata*, Rhodophyta.

INTRODUCTION

Fourteen species of *Porphyra* from Korea including *Porphyra seriata* Kjellman have been listed by Lee and Kang (1986). Since Ueda (1932) reported *Porphyra seriata* Kjellman from the west coast of Korea, it has been under intensive cultivation in Korea and Japan (Kang 1972; Miura 1988). At present, this alga has been a major culture crop and most popular economic cultivar species along the south and west coast of Korea. Especially, it has been famous as Dolkim (meaning wild *Porphyra* growing on the intertidal rocks in Korea). Because this is a temperate and cold water species it is common in Korea and Japan (Ueda 1932; Tanaka 1952; Kang 1966, 1972; Fukuhara 1968).

In some *Porphyra* species from Japan, the life history was defined completely in laboratory cultures (Iwasaki 1961; Kito 1978; Migita and Ito 1987; Iima and Migita 1990; Notoya *et al.* 1992; Notoya *et al.* 1993a; Notoya *et al.* 1993b; Matsuo *et al.* 1994). Although some data on field observations (Migita 1960; Fukuhara 1968; Kang 1972) and the effect of photoperiod on the liberation of conchospores (Shinmura *et al.* 1967) were reported, there are not much information on the life history such as temperature, photon flux density and photoperiod for *Porphyra seriata* Kjellman. Here we first report of the complete life history of *Porphyra seriata* Kjellman from Korea in laboratory culture.

MATERIALS AND METHODS

The mature foliose thalli of *Porphyra seriata* were collected in middle intertidal zone at Chindo in Chonnam Prefecture on 5 March 1996 (Fig. 1; Fig. 2A). From these thalli, zygotospores (Guiry 1990) were obtained to grow free living conchocelis colonies in culture. Zygotospores were cultured at six temperatures (5, 10, 15, 20, 25 and 30°C), four photon flux densities (10, 20, 40 and 80 μmol m^{-2} s^{-1}) and under two photoperiods of 14L:10D and 10L:14D. Free-living conchocelis were used to obtain conchospores and to initiate cultures of foliose phase. Foliose thalli were obtained from conchocelis colonies with conchosporangial branches cultured at 20°C and 40 μmol m^{-2} s^{-1} under photoperiod of 10L:14D. Modified Grund medium was used (McLachlan 1973) and renewed weekly.

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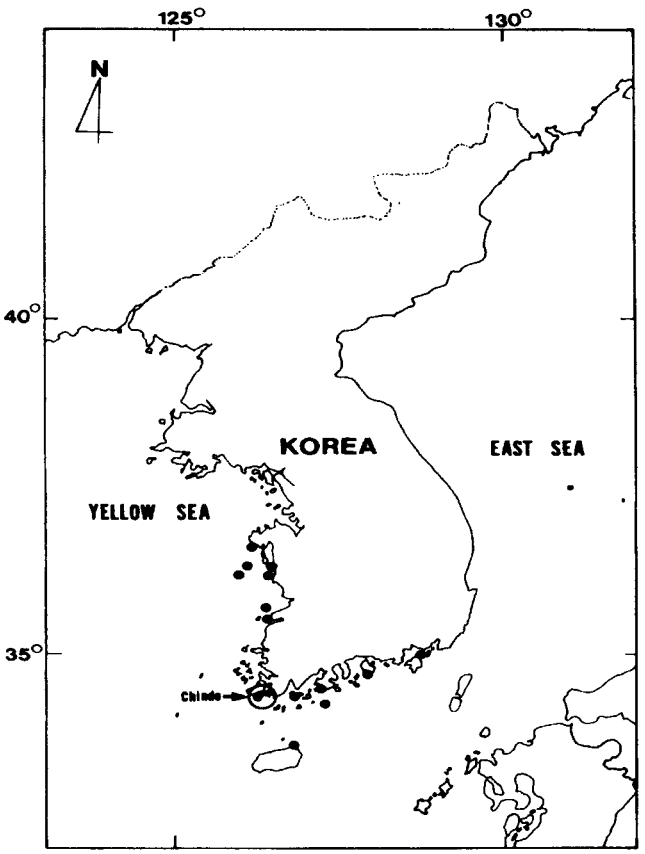

Fig. 1. Collection sites of *Porphyra seriata* Kjellman along the coast of Korea (○→: study, ●: References)

RESULTS AND DISCUSSION

Conchocelis phase

In *Porphyra seriata*, the zygotospores were germinated into the conchocelis colonies at 5-25°C (Fig. 2B), but at 30°C, they died within a week. Faster growth of conchocelis colonies were observed at 15-20°C and 40 μmol m^{-2} s^{-1} under both photoperiods. The maximum diameter of conchocelis colonies was about 3.5 mm at 20°C, 40 μmol m^{-2} s^{-1} under 14L:10D, and at 15°C, 40 μmol m^{-2} s^{-1} under 10L:14D within 10 weeks (Fig. 3).

Several studies on the conchocelis phase of ten species of Japanese *Porphyra* reported that conchosporangial branches were formed at 15°C to 25°C or 27°C in all the species studied (Kurogi and Hirano 1956; Kurogi and Akiyama 1966; Iwasaki and Sasaki 1971; Iima and Migita 1990; Notoya *et al.* 1992; Notoya *et al.* 1993a; Matsuo *et al.* 1994). Liberations of conchospores were induced by temperature decrease from 20°C to 15°C (Kurogi and Akiyama 1966; Iwasaki and Sasaki 1971; Iima and Migita 1990; Notoya *et al.* 1992). In case of other species such as *P. abbottae and P. perforata* (Waaland and Dickson 1983) and *P. rosengurtii* (Kapraun and Luster 1980), photoperiodic changes were necessary to induce spore liberation (Waaland and Dickson 1990). Their results agree with those of *P. suborbiculata* f. *latifolia* by Iwasaki and Sasaki (1971), *P. columbina* by Avila *et al.* (1986) and *P. spiralis* var. *amplifolia* by Kapraun and Lemus (1987). Especially, Iwasaki and Sasaki (1971) concluded that short period condition affected directly on the production of sporangia in the conchocelis phase. However, *P. seriata* we tested did not show any requirements of particular combinations of photoperiod and temperature to trigger the maturation of free-living conchocelis and the germination of conchosporangia. With regard to the maturation and liberation of conchocelis phase, our results did not agree with the previous results, but those agreed with the field observation on the liberation of conchospores in *P. seriata* (Fukuhara 1968).

Although conchospores were shed abundantly at 10°C and to a lesser extent at 5°C and 13°C, but not at 15°C or 20°C in field observation of the Canadian Atlantic species, *P. linearis* (Bird 1973), conchosporangial branches were produced at temperatures from 5-20°C in the laboratory culture of *P. linearis* (Bird *et al.* 1972).

As to the conchocelis phases in *Porphyra* species, the differences in temperature required for the formation of conchosporangial branches may be species specific properties, or may be the result of adaptation to the natural habitat conditions (Waaland *et al.* 1990).

Porphyra linearis, a winter species, spore release occurred at temperature of 13°C (Bird *et al.* 1972), while *P. miniata*, a summer species, that happened at 5°C (Chen *et al.* 1970). It is notable that spore release in other species is very specific characteristics and temperature related process.

The rate of conchosporangial branch formation in cohchocelis filaments at different combinations of temperature and photon flux density are presented in Fig. 4. Conchocelis colonies with conchosporangial branches (Fig. 2C) were produced within 9 weeks at all conditions tested except for those grown at 30°C, and formation of conchosporangia were faster at the photoperiod of 10L:14D than at the photoperiod of 14L: 10D. The formation rates increased with temperature, and those occurred 100% within 2 weeks at 25°C and all photon flux densities under both photoperiods. Especially, at 25°C and 20-80 μmol m^{-2} s^{-1} under 14L:10D and 10L:14D, conchosporangial branches developed into the prolonged shapes (Fig. 2D). In this culture study,

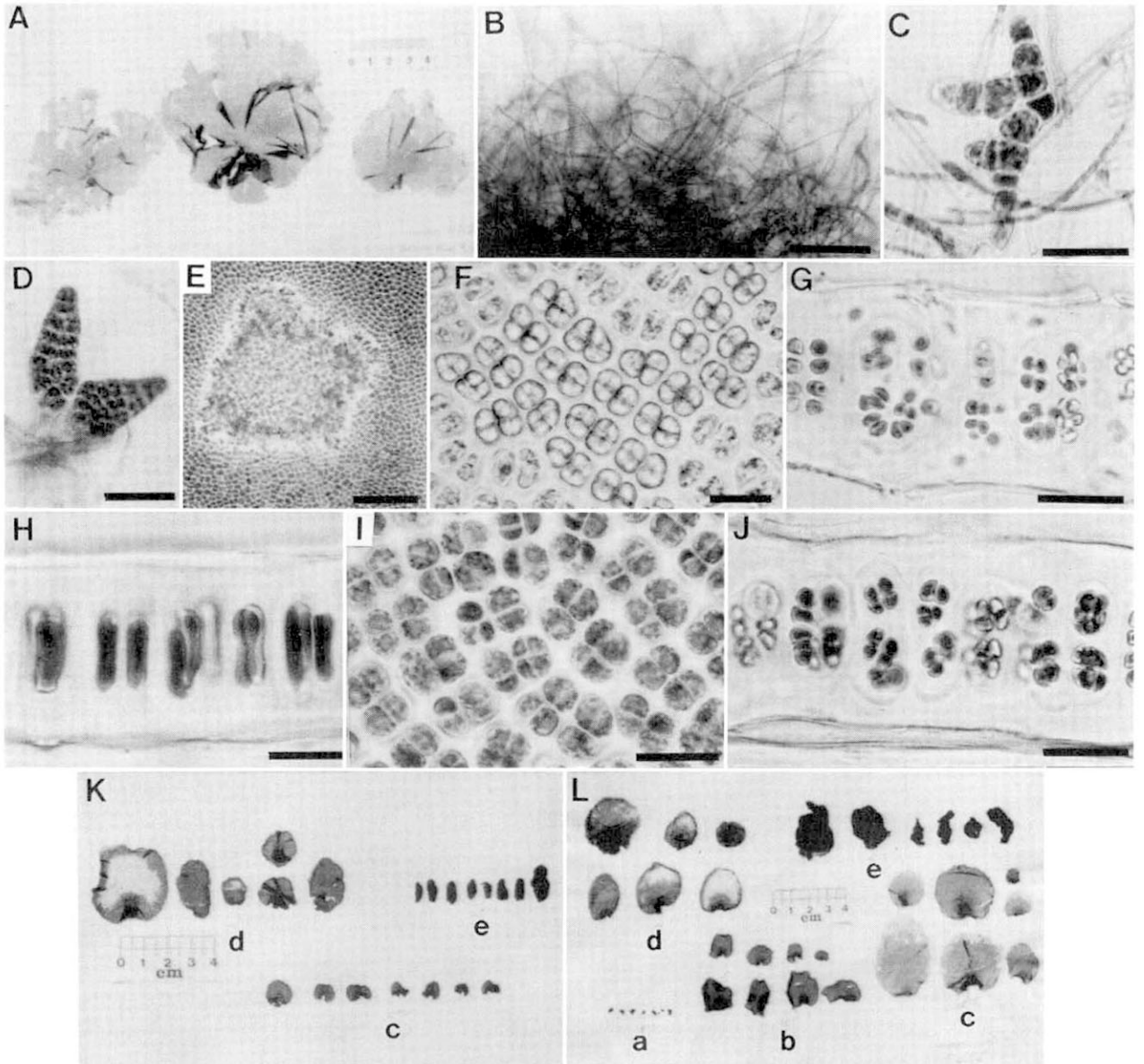

Fig. 2. Life history of *Porphyra seriata* Kjellman. (A) Mature foliose thalli of *Porphyra seriata* collected on 5 March 1996 at Chindo, Chonnam Prefecture, Korea; (B) Free-living conchocelis colony grown at 25°C and 20 μmol m^{-2} s^{-1} under 14L:10D; (C) Cochosporangial branches after 2 weeks at 20°C and 40 μmol m^{-2} s^{-1} under 10L:14D; (D) Conchospore germling afetr 1 week at 20°C under 10L:14D; (E) Surface view of rhombic spermatangial sorus; (F) Surface view of spermatangia; (G) Spermatangia in cross-section; (H) Cross-section showing carpogonia with prototrichogynes; (I) Surface view of zygotosporangia; (J) Zygotosporangia in cross-section; (K), (L) Foliose thalli of 15 weeks old grown in 14L:10D and 10L:14D showing different thallus shape, respectively, (a) 5°C (b) 10°C (c) 15°C (d) 20°C (e) 25°C. Scale bars: 100μm in B; 30μm in C, F, G, H and J; 50μm in D and I; 200μm in E.

conchospores were directly liberated without any stimulations from free-living conchocelis cultured at 10-25°C under all the photon flux densities and both photoperiods, and they germinated into young foliose thalli. This study indicates that the growth and maturation of conchocelis were affected by temperatures, photon flux densities and photoperiods, but the liberation of conchospores were not. But in this species, Shinmura *et al.* (1967) reported that liberation of conchospore was affected by photoperiod, and optimum photoperiods were dark periods of 14-16 hours. This may be the result of using the matured shell-living conchocelis with conchosporangial branches as experimental materials. Monospore production of conchocelis phase was not observed during the culture periods of 10 weeks.

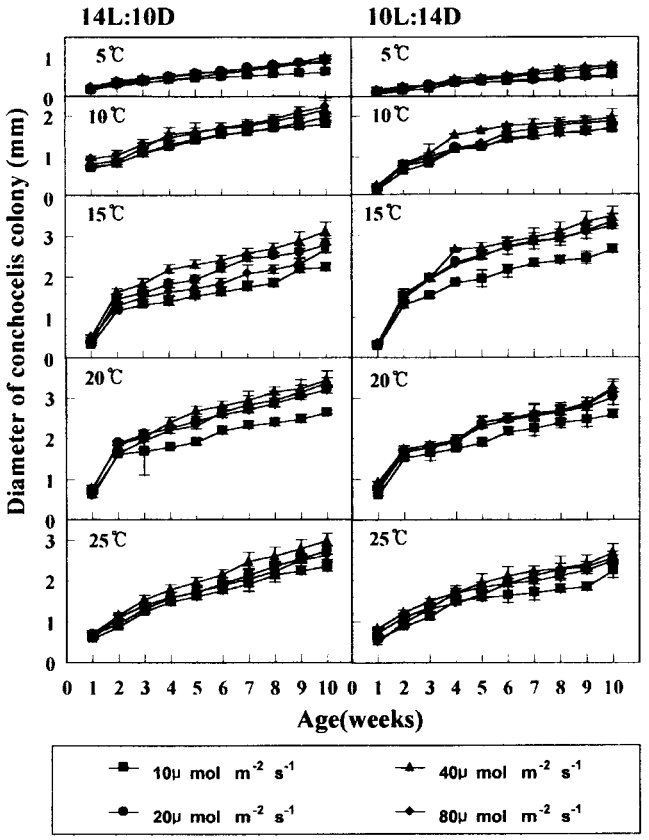

Fig. 3. Growth of conchocelis colony of *Porphyra seriata* at six temperatures (5-30°C) and four photon flux densities (10-80 μmol m^{-2} s^{-1}) under 14L:10D and 10L:14D. Vertical bars, standard deviations.

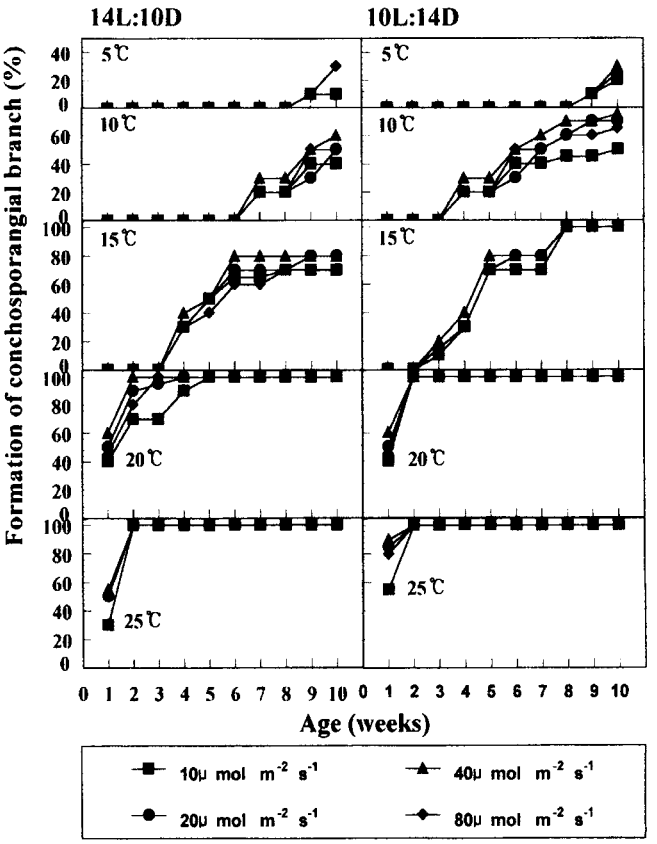

Fig. 4. Formation rates of conchosporangial branches in *Porphyra seriata* at five temperatures and four photon flux densities under 14L:10D and 10L:14D.

Foliose thallus phase

Foliose thalli (Fig. 2D) grew at 5-25°C, but they died within one week under both photoperiods at 30°C. The growth and maturation of foliose thalli were fastest at 15°C under 10L:14D and the foliose thalli either showed quite slow growth or did not mature for the culture periods of 15 weeks at 5°C (Fig. 5). Maturation of *Porphyra seriata* is much slower than other species cultured under same conditions (Notoya *et al.* 1993a). This result agrees with that of monoecious *Porphyra tenuipedalis* from Japan reported by Notoya *et al.* (1993b).

Based on the results of this study and the previous studies of other species in culture (Iwasaki 1961; Kurogi and Akiyama 1966; Avila *et al.* 1986; Notoya *et al.* 1993a; Matsuo *et al.* 1994), the growth and maturation of foliose thallus phase in *P. seriata* are much faster than those of other *Porphyra*. Spermatangial and zygotosporangial sori were formed in squarish patches at the upper marginal portion of thallus (Fig. 2E). Spermatangia and zygotospores were liberated from mature foliose thalli at 20°C under 14L:10D and 10-20°C under 10L:14D, respectively (Fig. 6). This species is usually found from October to April according to the field studies in Japan (Tanaka 1952; Migita 1960; Hukuhara 1968). In current study, *P. seriata* of Korea grew well at high temperatures over 20°C under both photoperiods. It suggests that this species may grow well at the broad range of temperatures. Notoya *et al.* (1993b) reported that monoecious *P. tenuipedalis* did not produce archeospores (Magne 1991; Kornmann 1991) in the culture studies of four species *Porphyra* from Japan. Fukuhara(1968) reported that this species did not liberate archeospores from natural thallus in his field observation. His report agrees with our results that archeospore were not liberated from foliose thallus at any culture conditions tested.

Hus' formula (Hus 1902) were observed; 64 (a/2, b/4, c/8) or 128 (a/4×b/4×c/8) in spermatangia (Fig. 2F, G) and 16 (a/2×b/2×c/4) in zygotosporangia (Fig. 2I, J), respectively. Dumbbell shaped carpogonia occurred in cultured thallus (Fig. 2H).

The shape of cultured foliose thalli were orbiculate with cordate or umbilicate basal part which is the same as wild thalli (Ueda 1932; Tanaka 1952; Hwang and Lee

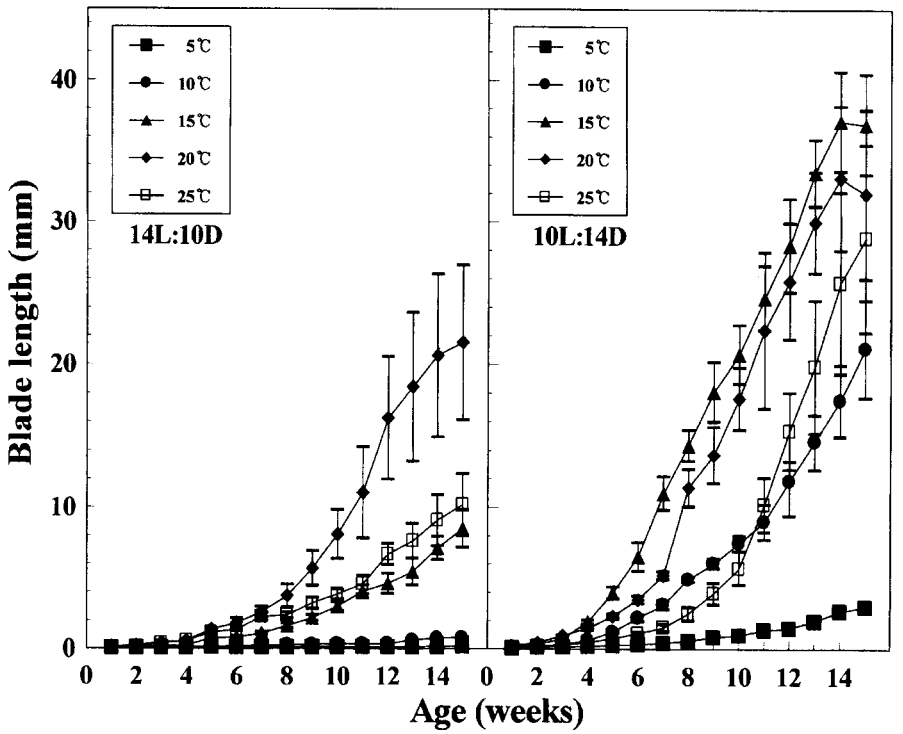

Fig. 5. Growth of foliose thalli in *Porphyra seriata* at five temperatures and 40 μmol m^{-2} s^{-1} under 14L:10D and 10L:14D. Vertical bars, standard deviations.

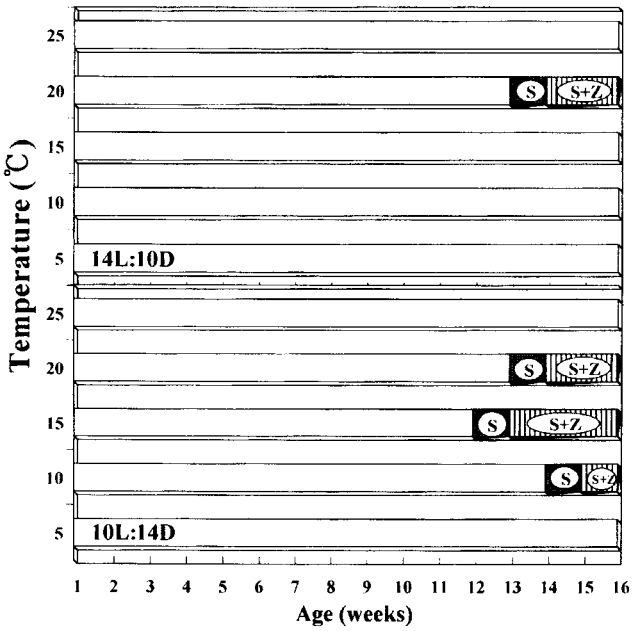

Fig. 6. Liberation of spermatia and zygotospores in relation to the age of cultured foliose thalli of *Porphyra seriata* at five temperatures under 14L:10D and 10L:14D.

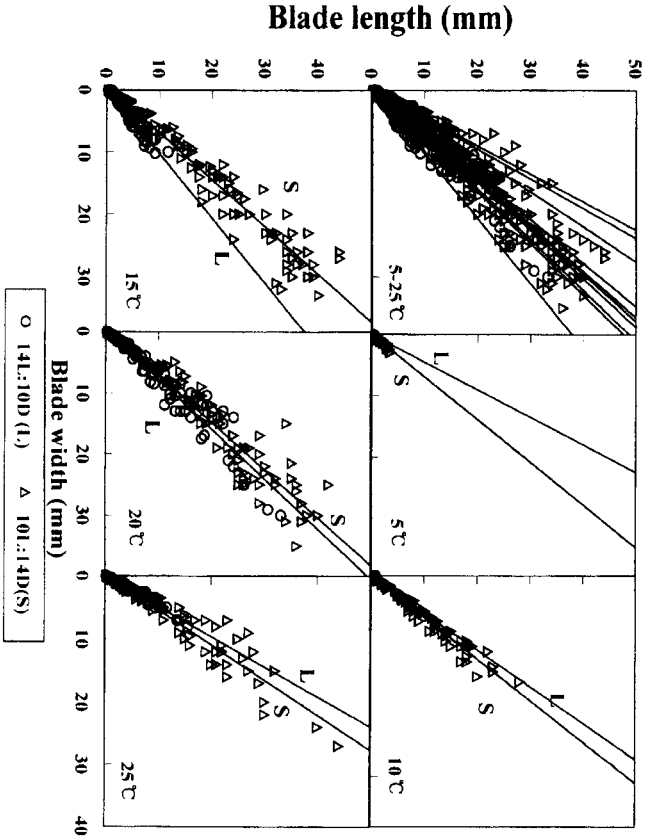

Fig. 7. Relationship between blade length and width *Porphyra seriata* at five temperatures and 40 μmol m^{-2} s^{-1} under 14L:10D and 10L:14D.

2001) at 15 and 20°C under both photoperiods while those of other culture conditions were elliptical or irregular (Fig. 2K, L).

In conclusion, this study indicates that the temperature

affected the growth and maturation of both phases. Although, this species may react very differently in a laboratory culture from that in a field environment, we may consider that *P. seriata* from Korea should well adopt to high temperature range of nature. Life history of this species is typical biphasic and as in *P. carolinensis* (Freshwater and Kapraun 1986), *P. columbina* (Avila *et al.* 1986), *P. kinositae* (Notoya *et al.* 1992), *P. lacerata* (Iima and Migita 1990), *P. linearis* (Bird *et al.* 1972), *P. miniata* (Chen *et al.* 1970), *P. rosengurtii* (Kapraun and Luster 1980), *P. spiralis* var. *amplifolia* (Kapraun and Lemus 1987), *P. suborbiculata* (Notoya *et al.* 1993a), *P. tanegashimensis* (Migita and Ito 1987), *P. tenera* (Iwasaki 1961) and *P. yezoensis* (Kito 1978). The type of life cycle of *P. seriata* was in accordance with the *P. lacerata* type (Notoya *et al.* 1993a) or the Kornmann type 2 (Kornmann 1991). Monospores and archeospores in both phases have not been identified.

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