Bull. Mar. Sci. Fish., Kochi Univ.
No. 22, pp. 65-79, 2003

Studies on *Porphyra suborbiculata* Kjellman (Bangiales, Rhodophyta) from Myanmar. I. The morphology and life history in culture

DAW AYE-MON-SEIN [1]*, DAW NI-NI-WIN [1], U. SAN-THA-HTUN [1],
U. SOE-HTUN [1]** and MASAO OHNO [2]

[1]*Department of Marine Science, Mawlamyine University, Mawlamyine, Myanmar*
[2]*Usa Marine Biological Institute, Kochi University, Usa-cho, Kochi, 781-1164, Japan*

Abstract: *Porphyra suborbiculata* Kjellman (Bangiales, Rhodophyta) collected from Mazin, Hlyaw-Gaung-Taung (Satt-Thwa) and Mwe-Taung, Zee Gyaing Village, the Mawtin Point, the Rakhine Coastal Region and Maungmagan, the Tanintharyi Coastal Region, Myanmar, is described, based on both the morphology and life history found in laboratory cultures and field. The materials used in this study show *Porphyra lacerata* type of life history: heteromorphic alternation of generations-conchocelis phase and monoecious leafy thalli phase. In addition, the developmental sequence of formation and germination of archeospores (bispores) in *P. suborbiculata* was acknowledged as asexual mode of reproduction usually occurred prior to the development of sexual structures. The taxonomy of *Porphyra suborbiculata* Kjellman from Myanmar and other related plants such as *P. crispata* Kjellman and *P. vietnamensis* Tanaka et Pham-Hoang Ho found in Asiatic waters is briefly discussed.

Key words: Bangiales, culture, life history, morphology, Myanmar, *Porphyra suborbiculata* Kjellman, Rhodophyta, taxonomy.

Introduction

In Myanmar, *Porphyra suborbiculata* Kjellman has been identified as *P. crispata* Kjellman by Min-Thein and Aung Myint (1975) from the rocky platforms at the upper intertidal zone of Mwe-Taung, near Zee Gyaing Village, Lat. 16°02' N, Long. 94°12' E, the Rakhine Coastal Region. Moreover, the conchocelis filaments of this species collected from the same areas have also been observed under the laboratory conditions by Soe-Htun and Zaw-Zaw-Pe (1986). Based on the herbarium specimens examined, *P. suborbiculata* distributes along both the Rakhine Coastal Region and the Tanintharyi Coastal Region but not along the Ayeyarwaddy Delta and the Gulf of Mottama (Martaban) Coastal Region due perhaps to the hyposalinity by the large volumes of fresh water from a large number of major rivers, namely, the Ayeyarwaddy, the Sittaung and the Thanlwin Rivers (Fig. 1).

Among the seaweeds of Myanmar, *Porphyra suborbiculata* Kjellman is considered as dependable natural resource of Myanmar (Soe-Htun 1998). However, there is no mariculture industry of *Porphyra* in Myanmar in the present time. Further studies on the biology of the local species of *Porphyra suborbiculata* Kjellman are still needed to establish *Porphyra* 'Nori' Industry in the unpolluted waters of Myanmar in future.

* Present address: Department of Fishery, Ministry of Life Stock and Fishery, Yangon, Myanmar
**Corresponding author

Interestingly, the high temperature resistant breakthroughs, new strains or breeds are successfully produced by protoplast fusion between the species of *Porphyra* such as *P. tenera, P. yezoensis, P. tenupedalis* and *P. suborbiculata* in Japan (Suto 1963; Matsumoto *et al.* 1992; Archihara and Nakashima 1995; Mizukami *et al.* 1995; Fujita and Rao 1997). It is hoped that this kind of hybrids using Japanese species of *P. tenera* or *P. yezoensis* and Myanmar species of *P. suborbiculata*, which luxuriantly grown in the summer time of monsoon periods in tropical areas, will increase the worldwide *Porphyra* production double in addition to the production of 69130 tonnes (dry weight) per year from the cultivation grounds especially in Japan, Korea and China of the subtropical and temperate regions, mainly in winter time (Critchley 1993; Oohusa 1993; Ohno and

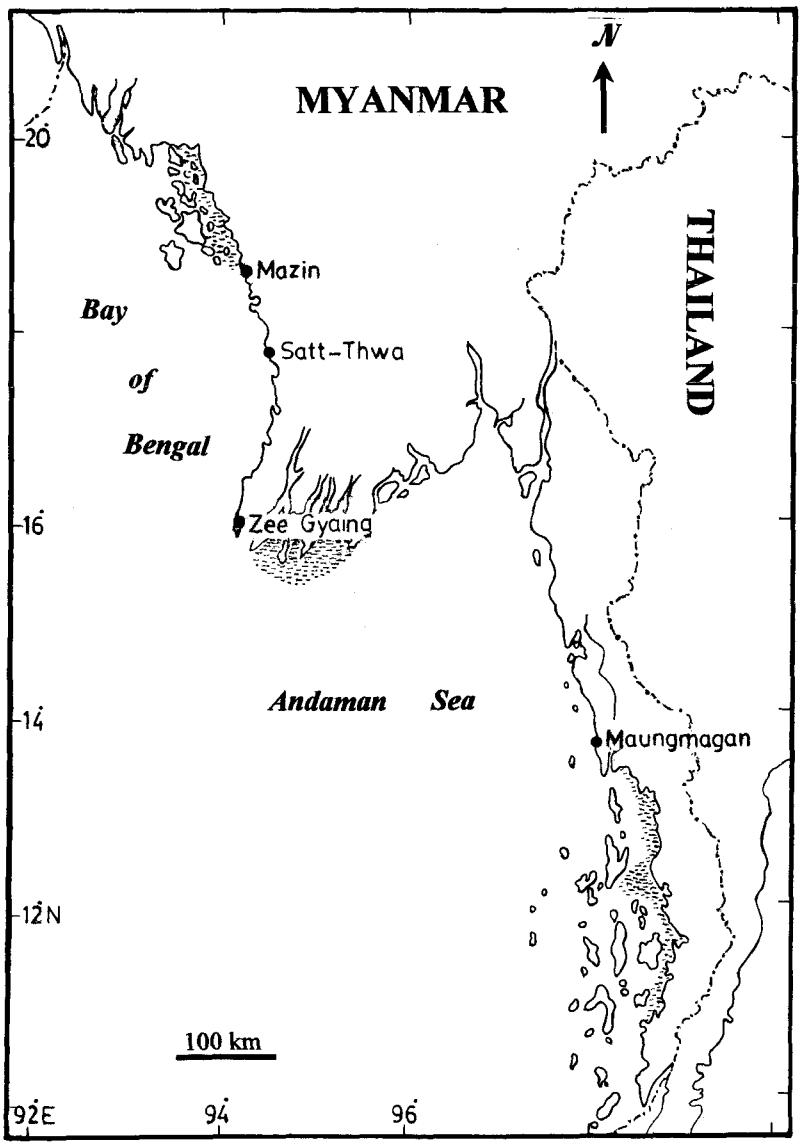


Fig. 1. Map showing the collection sites of *P. suborbiculata* Kjellman along the coastal areas of Myanmar.

Largo 1998; Sohn 1998; Wu 1998).

The objectives of this study on the economically important plant of *Porphyra suborbiculata* Kjellman grown commonly in Myanmar are to know external and internal morphology of the plant in details and to complete the biphasic and heteromorphic life history of the plant in the laboratory culture.

Materials and Methods

Morphological studies: Specimens collected from Mazin, Hlyaw-Gaung-Taung (Satt-Thwa), Mwe-Taung, Zee Gyaing Village and the Mawtin Point, the Rakhine Coastal Region and Maungmagan, the Tanintharyi Coastal Region, were liquid-preserved in 5% buffered formalin/seawater. Whole plants and sections prepared by hands using wax stick and double-edged razor blades, were mounted on glass slides in a solution of 1% aniline blue, 3% 1N HCl, 16% water with phenol added as preservative and 80% D.P.X. mountant (BDH). Herbarium sheets, microscope slides and liquid-preserved specimens are deposited in the Herbarium of Department of Marine Science, Mawlamyine University (MMB). The following herbarium specimens were examined: Rakhine Coastal Region: Mazin (Aung-Myint and Kyi-Shwe, 7. x. 1976; MMB 123); Hlyaw-Gaung-Taung (Satt-Thwa) (Ni-Ni-Win and Soe-Pa-Pa-Kyaw, 8. x. 2002; MMB 3930-3937; Tint-Lwin and S'. Aung-Myo-Htay, 8. x. 2002; MMB 3938-3945); Zee Gyaing (Aung-Myint, 18. ix. 1974; MMB 150); Mawtin Point (Zaw-Zaw-Pe, 27. viii. 1984; MMB 300); Zee Gyaing (Aye-Mon-Sein, 9. vi. 1997; MMB 3694-3698; 16. vii. 1997; MMB 3699-3704; 22. ix. 1997; MMB 3705-3706; 4. vii. 1998; MMB 3724-3731; 1. vi. 1998; MMB 3732-3736); Tanintharyi Coastal Region: Maungmagan (Min-Thein, 5. x. 1975; MMB 116-118).

Culture studies: The specimens used in this study were collected from the rocky platforms at upper intertidal zone of Mwe-Taung near Zee Gyaing Village (Lat. 16°02'N, Long. 94°12' E), the Cape Negrais, Ngaputaw Township, the Ayeyarwaddy Division, the Rakhine Coastal Region, Myanmar on June 9, 1997; July 4, 1997; September 22, 1997; June 1, 1998; July 4, 1998 and August 19, 1998. The plants were washed in seawater 3 - 4 times in the field, put into plastic bags contained with seawater and then transported to laboratory at Mawlamyine University within 2 days using ice-boxes.

In the laboratory, plants with archeospores or zygotospores were selected and washed by painting brushes in sterile seawater in order to eliminate the epiphytes and contaminants. The cleaned plants were dried on tissue paper and stored over night in dark condition. In the next morning, the plants were placed in a glass jar containing 30 ‰ of sterilized seawater together with small glass slides (1 cm x 1 cm) at room temperature. After 6 hours, the released archeospores or zygotospores settled onto the glass slides. The glass slides were checked for every 2 hours interval under a compound microscope to get the proper distance (ca. 500 (m) between the attached spores with the suitable density (about 30 - 40 spores per glass slide). And then, 20 archeospores or zygotospores in healthy conditions in pinkish-red color were selected and cultured in the Petri dishes (5 cm diameter) containing 20 ml of filtered and autoclaved seawater with different salinities, i.e., 5 ‰, 10 ‰, 15 ‰, 20 ‰, 25 ‰, 30 ‰, 35 ‰, 40 ‰ and 45 ‰, at different temperatures, i.e., 20°C, 25°C and 30°C, under different light intensities, i.e., 1.5 W/m^2, 2.5 W/m^2, 4.5 W/m^2, 5.0 W/m^2, 5.5 W/m^2 and 6.0 W/m^2, and 8:16 h L:D and 16: 8 h L:D photoperiods, respectively.

The length of 20 archeospores germlings and conchcelis filaments was measured (in μm)

under a compound microscope. Morphological structures of vegetative and reproductive cells, the successive stages in the development of archeospores into the young flattened plants and zygotospores into conchocelis filaments were photographed by the camera mounted to the Leitz microscope. In all experiments, light measurements were taken with YSI Model 65-A Radiometer and salinity was measured by using a salinity refractometer (Yagami Cat. No. 42 - 45 Japan).

The natural seawater from Setse coast was heated to get hypersalinities and hyposalinities by dilution with distilled water. Culture apparatus were rinsed several times with tap water and then cleaned with distilled water and finally autoclaved. The photoperiods and temperature regimes required were set, using Gallenkamp Incubators (INF 781-T). Provasoli's Enriched Seawater (PES) medium was used in all culture experiments (Provasoli, 1968).

Observations

General characteristics of *Porphyra suborbiculata* Kjellman collected from nature:

(a) Habitat and Seasonality

The plants of *Porphyra suborbiculata* Kjellman grow abundantly on rocks in the higher intertidal zone by means of discoidal holdfast. Sporelings, 1-3 mm high from conchospores, are commonly found in the field in the end of April. Normally, the growing season of larger plants starts in May and ends in October. Plants with archeospores occur only at the beginning of rainny season. Likewise, plants with spermatangia and zygotosporangia are encountered throughout the growing season. In nature, the luxuriant growth of these plants are observed in August, and the plants gradually disappear at the end of September, forming shell-boring conchocelis filaments grown in winter and summer seasons in the subtidal zone.

(b) Gross morphology:

(i) Vegetative structure

Thalli are monostromatic, undulate, purplish red in color, linear-lanceolate to obiculate in shape, with or without ramifications or incised lobes, 3 - 10 cm high and 3 - 8 cm broad with reniform or cordate base (Figs. 2-4), and inrolled with microscopically spinulate margins (Fig. 5). They attach to rocks by extraordinarily large discoidal holdfasts formed by oblong-capitate rhizoidal cells, 20 -35 μm long and 15 - 35 μm wide (Fig. 6). Vegetative cells each with a single stellate chloroplast are quadrate or angular with rounded corner to oblong in shape, 8-10 μm in length, 5-8 μm in width (Fig. 7). In surface view, these vegetative cells are irregularly arranged. A total thickness of vegetative parts is 30 - 50 μm (Fig. 8).

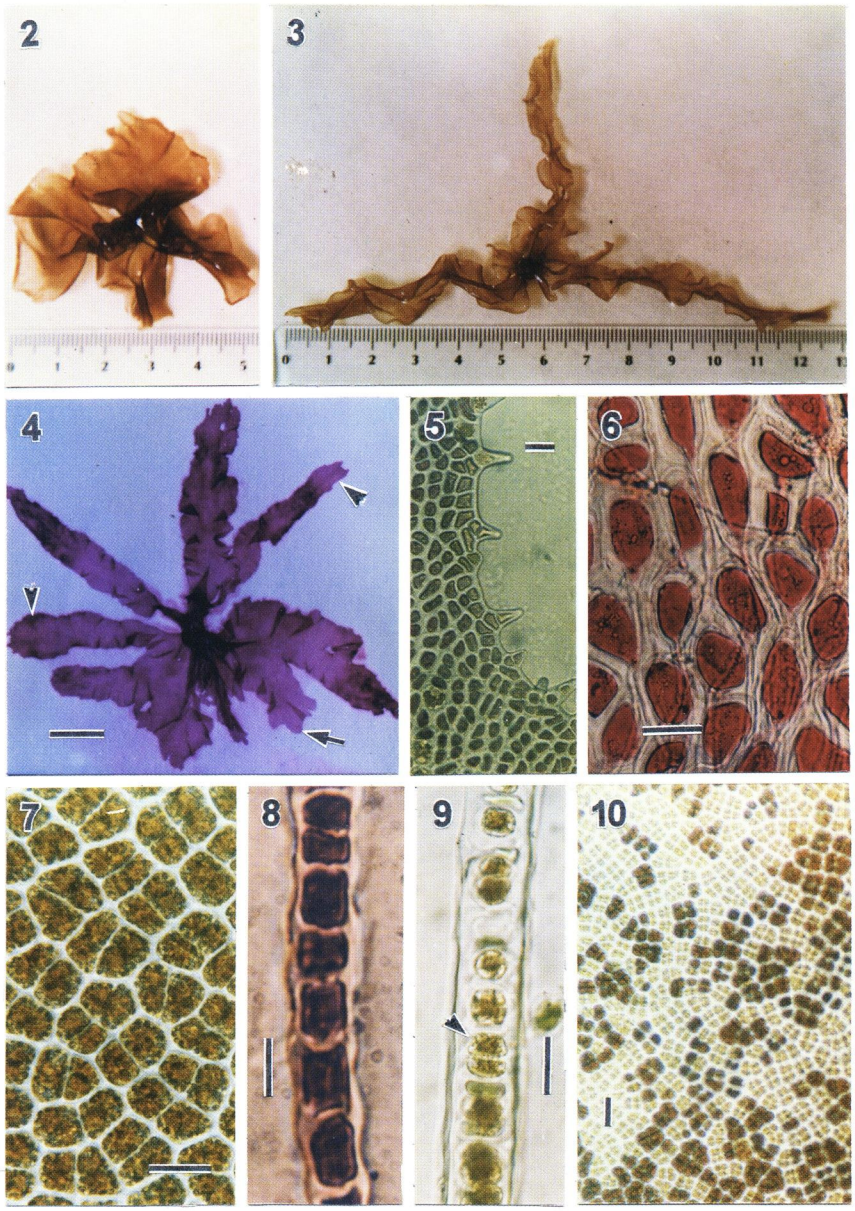
(ii) Reproductive structure

Plants are monoecious with intermixed spermatangia arranged by the division formula, 128 (a/2, b/8, c/8 or a/4, b/4, c/8) and zygotosporangia by the division formula, 32 (a/2, b/4, c/4) (Fig. 9). The archeospores measured about 15 - 20 μm in diameter, more or less spherical in shape, are formed in bisporangia (Fig. 10), which are also intermixed with spermatangial and zygotosporangial areas. Reproductive blades are 30-60 μm in thickness.

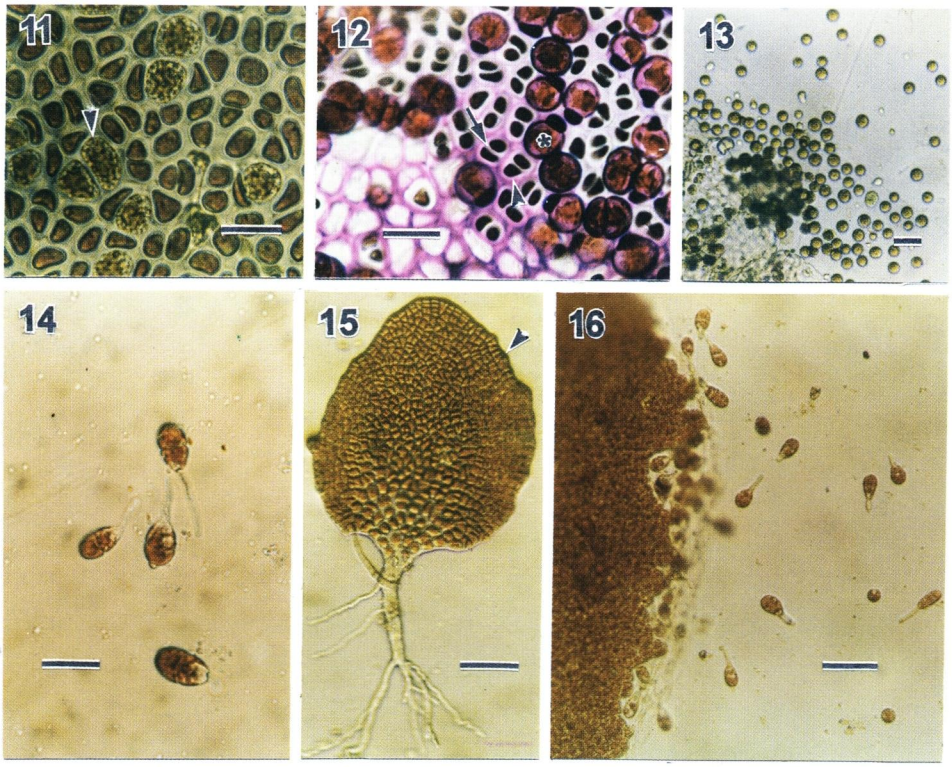
Life history of Porphyra suborbiculata Kjellman in culture:

(a) Development of archeospores and its germlings

Vegetative cell of *Porphyra suborbiculata* Kjellman is transformed successively into bisporangium, which normally consists of two archeospores (= bispores) both in all cultures and wild

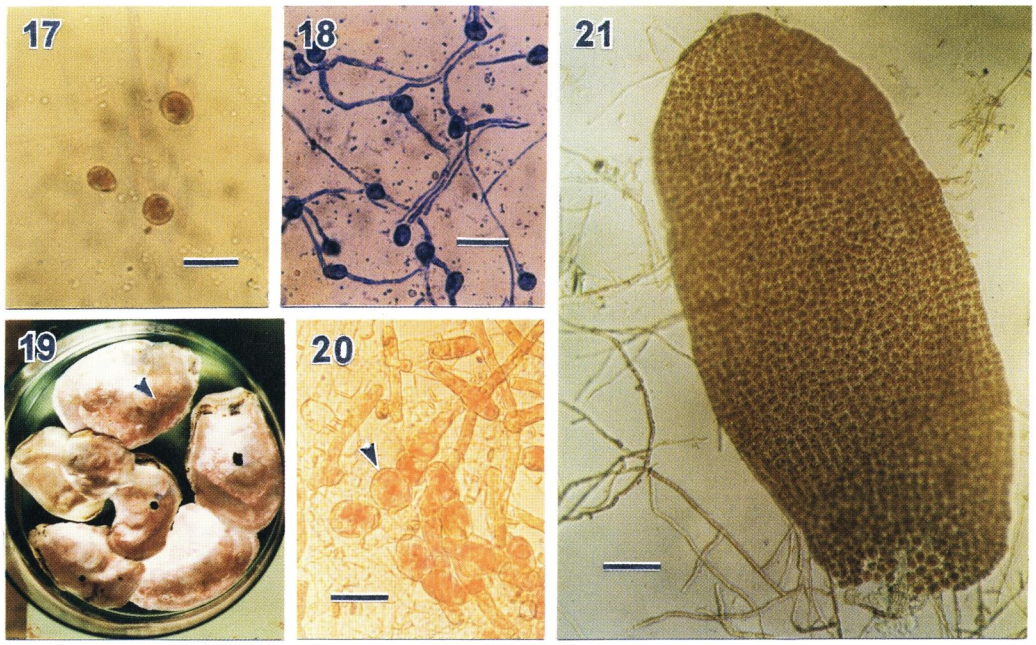


Figs. 2-10. Morphology of the plants of *Porphyra suborbiculata* Kjellman. Fig. 2. Orbiculate thalli collected at Zee Gyaing on September 22, 1997 (ruler scale in centimeter). Fig. 3. Linear-lanceolate thalli collected at Zee Gyaing on August 19, 1998 (ruler scale in centimeter). Fig. 4. Occasional occurrence of naturally divided lobes (arrow) and ramifications (arrowheads) of the blade on the plant collected at Hlyaw-Gaung-Taung (Satt-Thwa) on October 8, 2002 (scale bar = 1 cm). Fig. 5. Marginal portion of thallus showing microscopic spinulate processes (scale bar = 25 μm). Fig. 6. Basal cells in surface view with projecting rhizoidal filaments (scale bar = 50 μm). Fig. 7. Vegetative cells each with a single stellate chloroplast (scale bar = 10 μm). Fig. 8. Vegetative quadrate cells in transverse section (scale bar = 35 μm). Fig. 9. Transverse section of fertile blade showing archeospores (arrowhead) (scale bar = 30 μm). Fig. 10. Areas of intermixed spermatangia and zygotosporangia formed at the margin of the blade (scale bar = 35 μm).



Figs. 11-16. Formation and germination of archeospores in young plants of *Porphyra suborbiculata* Kjellman. Fig. 11. Formation of two archeospores (= bispores) (arrowhead) in a bisporangium (scale bar = 30 μm). Fig. 12. Two compacted and pigmented cells divided by a cross wall (arrow) within a cell wall which served as bisporangium (arrowhead), prior to the formation of archeospore (asteris) (scale bar = 30 μm). Fig. 13. Liberated archeospores (scale bar = 35 μm). Fig. 14. Growth of 3-day-old germlings of archeospore in bipolar manner (scale bar = 50 μm). Fig. 15. Fifteen-day-old plant with spinulate margin (arrowhead) (scale bar = 70 μm). Fig. 16. Newly germinated germlings at the margin of 19-day-old plant (scale bar = 70 μm).

plants (Fig.11) At first, a normal vegetative cell of the marginal portion concentrates its protoplasm and forms a compacted and pigmented cell. Later, a cross wall divides this cell into two compacted and pigmented cells within a cell wall (Fig. 12). And then, one of those cells gradually develops into archeospore, remaining the other cell dormant (Fig. 12). After completion of the formation of the archeospore from one of the compacted and pigmented cell, the remaining cell begins to give rise to archeospore again. Finally, two archeospores (bispores) are observed in a single sporangium, which serves as bisporangium (Fig. 12). The liberated archeospores (Fig. 13) from bisporangia of parent plants grew faster in salinity 10-25 ‰ at 30°C under 16:8 h L:D photoperiod under the light intensity of 5.6 W/m^2. The spores began to germinate after 1 day. After 2 days, the archeospore germlings developed in bipolar manner (Fig. 14). After 6-9 days, the margins of the germlings became spinulate (Fig. 15). After 12 days, the newly formed archeospores at the terminal portion of germlings were observed. The liberation of archeospores took place after another 15 days. These newly liberated archeospores developed into new germlings (Fig. 16), which also had completed their life cycle within 15 days. Accordingly, they repeated their life cycle in several times by asexual mode of reproduction in salinity 10- 25 ‰, under 16:8 h L:D



Figs. 17-21. Germination of zygotospores and, formation and development of young plant in *Porphyra suborbiculata* Kjellman. Fig. 17. Liberated zygotospores (scale bar = 25 μm). Fig. 18. Free-living conchocelis filaments cultured on the glass slide (scale bar = 50 μm). Fig. 19. Shell-boring conchocelis filaments in pinkish patches (arrowhead) on the shell. Fig. 20. Conchocelis filaments with swollen conchosporangia (arrowhead) (scale bar = 30 μm). Fig. 21. One-month-old leafy plant among the conchocelis filaments (scale bar = 70 μm).

photoperiod with the light intensity of 5.6 W/m2 at 20°C, 25°C and 30°C.

(b) Development of conchocelis filaments

The liberated zygotospores measured about 15-20 μm (Fig. 17) from the parent plants developed into conchocelis filaments on the glass slides or in free-living as well as shell-boring conchocelis filaments in pink color on the oyster shells in salinity 15 - 45 ‰ under 8:16 h L:D photoperiod with the light intensity of 5.6 W/m^2 at 20°C, 25°C and 30°C. After 6 days, one zygotospore with 2 - 3 primary filaments was normally observed (Fig. 18). The tertiary filaments were found after 9 days. After 12-15 days, the conchocelis filaments were slightly swollen and transformed into conchosporangia-like bodies (Fig. 20) in pink color from the terminal and intercalary cells of the filaments in salinity 40 ‰ and 45 ‰. After 3 months, these conchosporangia-like bodies were gradually transformed into matured conchosporangia. The conchospores liberated from conchosporangia, germinated into leafy thalli (Fig. 21) in 35 ‰ salinity under the short day photoperiod of 8:16 h L:D and 5.6 W/m^2 at 30°C after 6 months.

Discussion

Yoshida *et al.* (1997) compiled a catalogue of species of *Porphyra* with a total of 133 species recorded from many localities all over the world since the first establishment of the genus *Porphyra* by Agardh (1824). Moreover, Yoshida (1997) reported that the family Bangiaceae

comprises two genera, *Bangia* and *Porphyra* with reference to the history and future prospects of systematics of Bangiaceae, Rhodophyta. The species of *Porphyra* are currently characterized by a combination of morphological characters: (1) numbers of cell layers and chloroplasts; (2) shape of blades; (3) leaf margin entire or denticulate; (4) sexuality and distribution of male and female parts; and (5) division formula of antheridia (= spermatangia) and cystocarps (=zygotosporangia) with supplementary information on life history and habitat preference. Among the species of *Porphyra*, four species of *Porphyra* with microscopic spines, i.e., *P. okamurai* Ueda, *P. crispata* Kjellman, *P. dentata* Kjellman and *P. suborbiculata* Kjellman, were placed under the subgenus Euporphyra (Tanaka 1952). In addition, Tanaka and Pham-Hoang Ho (1962) proposed *P. vietnamensis* as a new species of *Porphyra* with dentate margins from Vietnam. Kurogi (1972) designated all these monostromatous species of Porphyras with spinulate processes on the margins under the subgenus Porphyra. Likewise, Tseng (1983) described six species of *Porphyra*, namely, *P. crispata* Kjellman, *P. dentata* Kjellman, *P. guangdongensis* Tseng et T. J. Chang, *P. haitamensis* T. J. Chang et B. F. Zheng, *P. suborbiculata* Kjellman and *P. vietnamensis* Tanaka et Pham-Hoang Ho, normally with serrate margins under the new section, sect. Dentata. Subsequently, Masuda *et al.* reported a total of 11 species of Porphyras with microscopic spinulated margins, i.e., *Porphyra suborbiculata* Kjellman, *P. crispata* Kjellman, *P. dentata* Kjellman, *P. okamurai* Ueda, *P. atropurpurea* (Olivi) De Toni, *P. denticulata* Levring, *P. marcosii* Cordero, *P. vietnamensis* Tanaka et Pham-Hoang Ho, *P. dentimarginata* C. Y. Chu et S. C. Wan, *P. guangdongensis* Tseng et T. J. Chang and *P. haitanensis* T. J. Chang et B. F. Zheng, from Asiatic waters. In general, among these species of Porphyras with serrate margins, three species of *Porphyra* grown in the tropical and subtropical areas of Asia, namely, *Porphyra crispata* Kjellman 1897, *P. suborbiculata* Kjellman 1897, *P. vietnamensis* Tanaka et Pham-Hoang Ho 1962 differ from the others in having lanceolate-orbiculate thalli.

Porphyra crispata Kjellman was reported from Vietnam (Dawson 1954; Pham-Hoang Ho 1969; Huynh and Nguyen 1998), the Philippines (Cordero 1974, 1977, 1987; Trono 1977), Taiwan (Wang and Chiang 1977), China (Tseng 1983) and Japan (Tanaka 1952; Segawa 1956; Chihara 1975; Yoshida *et al.* 1985, 1990, 1995). Although *P. crispata* Kjellman was reduced as the synonym of *Monostroma nitidum* after checking Kjellman's type materials of *Porphyra* spp. by Kurogi and Yamada (1986), the origin of the name of this species is still in use for the species of Porphyras collected from India (Mairh *et al.* 1998), the Philippines (Cordero 1987; Trono 1998), Thailand (Lewmanomont and Ogawa 1995; Lewmanomont 1998), and Japan (Yoshida *et al.* 1990, 1995).

Similarly, *Porphyra suborbiculata* Kjellman grows in the intertidal zone of tropical and subtropical waters of Asia: India (Untawale *et al.* 1983; Mairh *et al.* 1998), Sri Lanka (Ceylon) (Durairatnam 1961), Thailand (Lewmanomont and Ogawa 1995), the Philippines (Cordero 1974, 1977; Trono 1977; Masuda *et al.* 1991), Taiwan (Wang and Chiang 1977), China (Tseng 1983), Korea (Kang 1972) and Japan (Tanaka 1952; Miyata and Kikuchi 1997; Yoshida *et al.* 1997).

The Table 1 summarizes a comparison of main characteristics of *P. suborbiculata* Kjellman found in Asiatic waters. In the formation of reproductive structures, the number of zygotospores of *P. suborbiculata* grown in these countries is remarkably uniform in 32, except for 16 (a/2, b/2, c/4) formed in some plants of Taiwan, but not for spermatangia: 64 in the plants from the Philippines (Cordero 1974), Taiwan, China and Japan and; 128 in the plants of Myanmar and the Philippines (Masuda *et al.* 1991). Surprisingly, even for the plants of *P. suborbiculata* collected from the Philippines, it was noted that there were two division formulas of spermatangial formation: (1) 64 (a/4, b/4/, c/4) (Cordero 1974); and (2) 128 (a/4, b/4, c/8) (Masuda *et al.* 1991) but division formula for zygotospore was strikingly unique by 32 (a/2, b/4, c/4) in both studies.

Table 1. A comparison of the plants of Porphyra suborbiculata Kjellman growing in Asiatic waters

Characters	*P. suborbiculata*							
	Sri Lanka	Myanmar	Philippines		Taiwan	China	Japan	
	(Durairatnam 1961)	(The present authors)	(Cordero 1974)	(Masuda *et al.*1991)	(Wang et al. 1977)	(Tseng 1983)	(Tanaka 1952)	(Miyata et al. 1997)
Seasonality	—	May- October	Nov - Feb	Nov - Feb	Dec, Feb, April	—	—	Sept. or Oct. to May
Thallus shape	ovate or reniform	linear-lanceolate to rounded	reniform	reniform, round or funnel-shaped	round, reniform, to elliptical	—	ovate or reniform	orbiculate or round and reniform
Thallus size	3-10 cm high, 3-8 cm wide	3-10 cm high, 3-8 cm wide	6.0 cm high, 3.5 cm wide	1-3 cm high —	1.5-4.5 cm high, 2.5-6.5 cm wide	2-6 cm high, 10 cm wide	3-10 cm high, 3-7 cm wide	4-6 cm high and width
Thallus division	—	present, with or without ramification	—	present	—	—	—	—
Thallus margin	—	inrolled, undulate	slightly undulate	rolled toward one side	entire or undulate	rolled inward	slightly undulated	inrolled
Color	—	purplish red	purplish red	purplish red	red	purple-red	light pink or purplish red	glossy black or deep purple to brown
Thickness of vegetative part	28-50 μm	30-50 μm	22.8-30.4 μm	35-45 μm	—	40 μm	30-48 μm	52-57 μm
Arrangement of vegetative cell in surface view	angular	irregularly arranged, 8-10 μm long, 5-8 μm wide	regularly arranged, 7.6-11.4 μm in diameter	polygonal;, 20-30 μm long, 12-22 μm wide	—	—	—	—
Vegetative cell in cross section	quadrate with rounded angles higher than broad	angular to oblong, higher than broad	angular, rounded angles	quadrate with rounded angle; 20-30 μm high, 15-30 μm wide	—	— 28-30 μm high 15-25 μm diam.	quadrate with rounded angles; slightly higher than wide	angular, quadrate with rounded angles, 12-20 μm long, 7-14 μm wide
Shape and size of rhizoidal cells	—	angular to oblong, capitate, 20-35 μm long, 15-35 μm wide	oblong, angulato-capitate, 30.2 μm long, 11.4-26.6 μm wide	angular to oblong, capitate;20-60 μm long, 20-35 μm wide	—	orbiculate	angulate capitate	polygonal or capitate19-31 μm long, 14-19 μm wide
Thickness of fertile parts	—	30-60 μm	—	35-50 μm	—	—	40-50 μm	—
Female and male areas	—	intermixed marginally	both located marginally	splashed	lower margin of frond; ♀ area, upper margin of frond	splashed marginally	splashed	♂ area, marginal stripe shaped
Number and division formula of zygotosporangia	32 (no data)	32 (a/2,b/4,c/4)	32 (a/2,b/4,c/4)	32 (a/2,b/4,c/4)	16 (a/2,b/2,c/4) or 32 (a/2,b/4,c/4)	32 (a/2,b/4,c/4)	32 (a/2, b/4, c/4)	32 (a/2, b/4, c/4)
Number and division formula of spermatangia	—	128 (a/4,b/4,c/8)	64 (a/4,b/4,c/4)	128 (a/4,b/4,c/8)	64 (a/4,b/4,c/4)	64 (a/4,b/4,c/4)	64 (a/4, b/4, c/4)	64 (a/4, b/4, c/4)

Likewise, *Porphyra vietnamensis* Tanaka et Pham-Hoang Ho was also recorded from India (Rao 1969; Rao and Sreeramulu 1970; Krishnamurthy *et al.* 1970; Dixit 1972; Untawale *et al.* 1983; Mairth *et al.* 1998), Thailand (Ogawa and Lewmanomont 1978, 1979, 1984; Imada and Abe 1980; Lewmanomont and Chittpoolkusol 1993; Lewmanomont and Ogawa 1995; Lewmanomont 1998), and China (Tseng 1983; Wu 1998). Moreover, Ogawa and Lewmanomont (1978) reported that the carpospores of *Porphyra vietnamensis*, which was collected in the vicinity of Songkha in southern Thailand, germinated into conchocelis filaments and the conchosporangia initials were formed on them. Accordingly, the monospores were liberated from mature thalli and developed into the young leafy thalli with denticulate margin. Ogawa and Lewmanomont (1979) stated that the rainy season affects a great influence on the growth of *P. vietnamensis* in Thailand. They considered that the *Porphyra vietnamensis* distributes not only in the coast of Thailand, but also in the coast of Myanmar (Burma) and Malaysia. Subsequently, Lewmanomont and Chittpoolkusol (1993) have completed the life history of *P. vietnamensis* Tanaka et Pham-Hoang Ho from Thailand through the laboratory cultures, showing the *Porphyra lacerata* type of life history.

In Myanmar, Min-Thein and Aung-Myint (1975) firstly reported *Porphyra crispata* Kjellman collected from Mwe-Taung, Zee Gyaing and the Mawtin Point areas at the southern parts of the Rakhine Coastal Regions. However, Aye-Mon-Sein (1999) proposed it under the name of *P. suborbiculata* Kjellman for the *Porphyra* species of Myanmar based on detailed studies of morphology and cultures under various environmental conditions created in the laboratory. The local *Porphyra suborbiculata* Kjellman shows linear-lanceolate to ovate in shape with distinctly formed spinulate processes at the margins. When matured, the reproductive cells such as archeospores, spermatangia and carpogonia are intermixed together at the upper part of the thallus. Formulas of division varied for the formation of spermatangia from 128 (a/4, b/4, c/8) by Aye-Mon-Sein (1999) to 128 (a/2, b/8, c/8) by Min-Thein and Aung-Myint (1975) but the total number was the same in both investigations. However, the formulas of division and the total number of zygotospores were uniquely 32 by the formula, (a/2, b/4, c/4) in each zygotosporangium in both studies.

Likewise, *P. suborbiculata* Kjellman showed spermatangial patches arranged in 64 -128 spermatangia together with zygotosporangial patches also arranged in 32 zygotospores whereas the related plants of *P. vietnamensis* provided with 64 antheridia and 8 zygotospores (Tanaka 1952; Tanaka and Pham-Hoang Ho 1962; Cordero 1974; Tseng 1983; Masuda *et al.* 1991). Moreover, *P. vietnamensis* Tanaka et Pham-Hoang Ho has peculiar type of the ramifications from the basal to middle portion of the thallus. On the other hand, in some cases, this type of ramification and deeply divided lobes of the blade are also found in some plants of *Porphyra suborbiculata* of Myanmar, showing the regeneration of the thalli by diffused meristems, due perhaps to the effects of damages by grazers, especially in younger stages of the plants. Except for the numbers of spermatangia and zygotosporangia, and the ramification, the general morphology of species of Myanmar *Porphyra suborbiculata* Kjellman closely resembles to those of *P. vietnamensis* Tanaka et Pham-Hoang Ho from Thailand.

According to Miura (1968), Kurogi (1972), Suto (1972) and Nisizawa (1987), by contrast, the number and division formulas of spermatangia and zygotosporangia, shape, color, thickness of the blades and seasonality varied with the age and phycogeographical regions. Hence, these characteristics, which were influenced by various environmental parameters of different latitudes, could not be used as reliable taxonomic criteria for the identification of Porphyras growing in the Asiatic waters. Likewise, the descriptions for the same species also slightly varied by the authors who lived in different geographical areas (e.g., Table 1). Therefore, it was considered that the external

morphology such as the seasonality, shape, color and thickness of blades as well as the internal structures such as formation of the number of spermatangia and zygotosporangia, were not reliable for the identification of Porphyras.

Although there were many differences of these unreliable characteristics between the remaining two related genera of *P. suborbiculata* Kjellman and *P. vietnamensis* Tanaka et Pham-Hoang Ho, growing in tropical waters of the Bay of Bengal and the Andaman Sea, the plants collected from Myanmar waters are identified as *P. suborbiculata* Kjellman 1897 rather than *P. vietnamensis* Tanaka and Pham-Hoang Ho 1962. In comparison, Ogawa and Lewmanomont (1984) described a new record of *P. vietnamensis* Tanaka et Pham-Hoang Ho collected from Surin Island, the outermost region of the Andaman Sea whilst Min-Thein (unpublished data of herbarium specimens examined) collected *P. suborbiculata* from Maungmagan, in the inner region of the Andaman Sea. On the other hand, Durairatnam (1961) described the monospecific species of *Porphyra* from Ceylon (Sri Lanka) as *P. suborbiculata* Kjellman 1897 for the species growing in the Bay of Bengal, the Indian Ocean Regions (IOR).

In the present study, the life history of *P. suborbiculata* Kjellman from Myanmar in culture and wild shows the biphasic heteromorphic *Porphyra lacerata* type of life history proposed by Notoya (1997): filamentous sporophytes (conchocelis phase) and monoecious foliose gametophytes bearing intermingled male and female reproductive cells (leafy thalli phase). In addition, Kusakabe (1929), Notoya *et al.* (1992, 1993), Matsuo *et al.* (1994) and Notoya and Kim (1996) reported the asexual mode of reproduction by the formation of archeospores (= formerly described as neutral spores) in *Porphyra suborbiculata* from Japan in the Pacific Ocean. In this study, that kind of mode of reproduction was also firstly recorded in the species of *P. suborbiculata* from Myanmar in the Indian Ocean Regions (IOR). The development of archeospores of *P. suborbiculata* of Myanmar also revealed the same pattern of it found in *P. leucosticta* (Berthod 1881; Fritsch 1945), and *P. yezoensis* and *P. tenera* (Kurogi 1961) by a vertical division of the mother cell into 2 to 4 cells perpendicular to the surface.

Moreover, Soe-Htun and Zaw-Zaw-Pe (1986) first observed the zygotospores gave rise the shell-boring conchocelis-phase and no formation of conchosporangia occurred on the conchocelis filaments in 30 ‰ salinity at 30-35°C under continuous light of 5 W/m^2 in *P. suborbiculata* (= formerly identified as *P. crispata*). In this study, however, the development of conchosporangia were normally formed on the conchocelis filaments in 25-30 ‰ salinity at 25-30°C under 16:8 h L:D and 5 W/m^2, resembling it to that of *P. suborbiculata* from Japan (Migita 1961). Furthermore, the conchocelis filaments from zygotospores of the local *P. suborbiculata* easily penetrate into the shells of mollusks (Fig. 19) and then show the luxuriant growth of it but not in the related *P. suborbiculata* forma *latifolia* of Japan, according to Iwasaki and Sasaki (1971).

In general, the biphasic heteromorphic life history along with the asexual mode of reproduction, and the external and internal morphologies of thalli in Myanmar species of *Porphyra suborbiculata* are closely similar to that of *P. vietnamensis* (Ogawa and Lewmanomont 1978, 1979; Imada and Abe 1980; Masuda *et al.* 1991; Lewmanomont and Chittpoolkusol 1993), except for the numbers of reproductive organs and deeply divided lobes or ramifications of the blade. Further studies such as isozyme, cytology, transplanting and crossing experiments between *P. vietnamensis* Tanaka et Pham-Hoang Ho and *P. suborbiculata* Kjellman are needed to be solved the systematics problems on these related species, luxuriantly growing in the rainy season of tropical areas. Accordingly, the ranges of variations on size, shape, thickness and life span of vegetative cells by diffused meristems, and reproductive cells under various environmental conditions

should be assigned for the species of Porphyras grown in Asiatic waters.

Acknowledgements

We would like to thank Professor Dr. Swe-Thwin, Head of Department of Marine Science, University of Mawlamyine, for support in preparing this work in the Phycological Research Laboratory. We are indebted to Dr. Min-Thein, Director, Microalga Biotechnology Department, Myanmar Pharmaceutical Factory (MPF), Yangon, Myanmar, for constructive criticism on the manuscript and making valuable suggestions. Special thanks are due to Dr. Tadao Yoshida, Professor Emeritus, Graduate school of Science, Hokkaido University, for invaluable comments on the identification of the species of *Porphyra* from Myanmar. The senior author, *Daw* Aye-Mon-Sein, wishes to express her personal gratitude to her beloved parents, U Ban-Sein and *Daw* Aye-Nyein for their financial support during the course of this study.

References

Achiha, H. and Nakashima, Y. 1995. Interspecific hybrid of isolated protoplast between *Porphyra suborbiculata* and *P. tenuipedalis* by electrofusion method. Jpn. J. Phycol. (S_rui) 43: 223-226.

Agardh, C. 1824. Systema algarum. Berlingianis, Lund: 312 pp.

Aye-Mon-Sein, Daw. 1999. Laboratory culture of the red alga, *Porphyra crispata* Kjellman. Unpublished M.Sc. Thesis. Department of Marine Science, Mawlamyine University.

Berthold, G. 1881. Zur Kenntnis der Siphoneen und Bangiaceen, Mitt. Zool. Stat.,Neapel, (I):72-82.

Chihara, M. 1975. The seaweeds of Japan (Gakken Illustrated Nature Encyclopedia). Gakken Co., Ltd.

Cordero, Jr. P.A. 1974. Phycological observations- I. Genus *Porphyra* of the Philippines, its species and their occurrences. Bull. Jap. Soc. Phycol. Vol. XXII, No.4: 134-142.

Cordero, Jr. P.A. 1977. Studies on Philippine marine red algae. Specl. Publ. Seto Mar. Biol. Lab., Series IV. Contr. Seto Mar. Biol. Lab. No. 632: 258 pp., 28 pls.

Cordero, Jr. P.A. 1987. Sea vegetable algae and their utilization in the Visayas, Philippines. *In*: Umezaki, I. c Scientific surveys of Marine algae and their resources in the Philippine Islands: 87-88.

Critchley, A. T. 1993. Introduction: Seaweed resources. *In*: Ohno, M. and Critchley, A.T. (Eds.), Seaweed cultivation and marine ranching. Kanagawa International Fisheries Training Centre. Japan International Cooperation Agency (JICA): 1-16.

Dawson, E.Y. 1954. Marine algae in the vicinity of the Institut Oceanographique de Nhatrang, Vietnam. Pac.Sci. 8 (4): 373-469, 63 figs.

Dixit, S.C. 1972. Species list of Indian marine algae IV. The Journal of the University of Bombay. XLVIII-XLIX (75-76): 56-80.

Durairatnam, M. 1961. Contribution to the study of the marine algae of Ceylon. Fish. Res. Stn. Bull. 10: 181 pp., 32 pls.

Fritsch, F.E. 1945. The Structure and Reproduction of the Algae. The University Press: Cambridge, II: 939 pp.

Fujita, Y. and Rao, U.S. 1997. Genetic improvement of *Porphyra* through cell culture techniques: Present status and future prospects. *In*: Miyata, M. and Notoya, M. (Eds.), Proceedings of the 8th Natural History Symposium: Present and future on the biology of *Porphyra*. Nat. Hist. Res. Special Issue No. 3: 47- 56.

Huynh, Q.N. and Nguyen, H.D. 1998. The seaweed resources of the Vietnam. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency: 62-69.

Ho, P-H. 1969. Marine algae of South Vietnam. Trung-Tam Hoc-Lieu Xuat-Ban. Saigon: 558 pp (In Vietnamese).

Imada, O. and Abe, T. 1980. Formation and germination of conchospores in *Porphyra vietnamensis*. Bulletin of the Japanese Society of Scientific Fisheries. 46(8): 1051.

Iwasaki, H. and Sasaki, N. 1971. The Conchocelis phase of *Porphyra suborbiculata* forma *latifolia*. Proceedings of the Seventh International Seaweed Symposium Sapporo, Japan. University of Tokyo Press: 364-367.

Kang, J.W. 1972. Cultivated *Porphyra* in Korea. Nisizawa, K., Arasaki, S., Chihara, M., Hirose, H., Nakamura, Y. and Tsuchiya, Y. (Eds.), Proceedings of the Seventh International Seaweed Symposium. Sapporo, Japan, August 8-12, 1971. Tokyo University Press: 108-110.

Kurogi, M. 1961. Yoshoku amanori no shurui to sono seikatsushi (amanori-rui no seikatsushi no Kenkyu). [Types of cultured *Porphyra* and their life history (Study on the life history of *Porphyra*, Report No.2)], Ibid. (18): 115 pp (In Japanese).

Kurogi, M. 1972. Systematics of *Porphyra* in Japan. *In*: Abbott, I.A. and Kurogi, M. (Eds.), Contributions to the systematics of Benthic Marine Algae of the North Pacific. Japanese Society of Phycology, Kobe, Japan: 167-191.

Kurogi, M. and Yamada, I. 1986. New knowledges obtained by the observation on the original specimens of F. R. Kjellman: Japanska arter af slägtet *Porphyra* . Jap. J. Phycol. 34: 62 p (In Japanese).

Kjellman, F.R. 1897. Japanska aster of slägtet *Porphyra*. Svenska Vitensk., Handl. 23 (afd. III, 4): 1-34, 5 pls.

Krishnamurthy, V. and Joshi, H. V. 1970. A Check-List of Indian Marine Algae. Central Salt and marine Chemicals Research Institute (CSMCRI) Publication, Bhavnagar: 36 pp.

Kusakabe, D. 1929. Asakusanori no yoshoku ni tsuite (On the culture of *P. tenera*), Suiko Kenkyu Hokoku) Journal of Imperial Fisheries Institute, Tokyo). 25(2): 17-26 (In Japanese).

Lewmanomont, K. and Chittpoolkusol, O. 1993. Life history of *Porphyra vietnamensis* Tanaka and Pham-Hoang Ho from Thailand. Hydrobiologia 260/261: 397-400.

Lewmanomont, K. and Ogawa, H. 1995. Common seaweeds and seagrasses of Thailand. Faculty of Fisheries, Kasetsart University.

Lewmanomont, K. 1998. The seaweed resources of Thailand. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 70-78.

Matsuo, M., Notoya, M. and Aruga, Y. 1994. Life history of *Porphyra suborbiculata* Kjellman (Bangiales, Rhodophyta) in culture. La mer. 32: 57-63.

Mairh, O.P., Reddy, C.R.K. and Kumar, R.K. 1998. The seaweed resources of India. *In*: Critchley, A.T. and Ohno. M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 110-126.

Masuda, M., Ohno, M. and Trono, G. C. Jr. 1991. A taxonomic assessment of *Porphyra suborbiculata* Kjellman, a food species from the Philippines. Jpn. J. Phycol. (S_rui) 39: 375-380.

Matsumoto, M., Kawashima, Y. and Tokuda, H. 1992. Saibo yugo ni yoru amanori rui no hinshu kairyo (Improvement of *Porphyra* through protoplast fusion). Abstracts for the 1st Marine Biotechnology Meeting, p. 45. May 1992, Shimidzu, Japan (In Japanese).

Matsumoto, M., Kawashima, Y. and Fucui, H. 1995. Saibo yugo ni yoru koon taisei no donyu (Introduction of high temperature resistance through protoplast fusion). Kaiyo monthly 27(11): 677-682 (In Japanese).

Migita, S. 1961. Studies on 'Plant' of conchocelis-phase of *Porphyra*. Bulletin of the Faculty of Fisheries. Nagasaki University No, 11: 128-136.

Min-Thein, U. and Aung-Myint, U. 1975. *Porphyra crispata* Kjellman (Rhodophyta, Bangiales) from Burma. Proceedings of the Burma Research Congress: 7 pp.

Miura, A. 1968. *Porphyra katadai*, a new species from Japanese coast. J. Tokyo Univ. Fish. 54: 55-59.

Miyata, M. and Kikuchi, N. 1997. Taxonomic study of *Bangia* and *Porphyra* (Bangiaceae, Rhodophyta) from Boso Peninsula, Japan. *In*: Miyata, M. and Notoya, M. (Eds.), Present and future on biology of *Porphyra*. Nat. Hist. Res., Special issue No.3: 19-46.

Mizukami, Y., Okauchi, M., Kito, H., Ishimoto, S., Ishida, T. and Fuseya, M. 1995. Culture and development of electrically fused protoplasts from marine red algae, *Porphyra yezeonsis* and *P. suborbiculata*. Aquaculture 132: 361- 367.

Nisizawa, K. 1987. Preparation and marketing of seaweeds as foods. *In*: McHugh, D.J. (Eds.), Production and

utilization of products from commercial seaweeds. FAO Fish. Tech. Pap. (288): 189 pp.

Notoya, M., Kihuchi, N., Matsuo, M., Aruga, Y. and Miura, A. 1992. Culture studies of four species of *Porphyra* (Rhodophyta) from Japan. Abstracts and Programme of XIVth International Seaweed Symposium: 109 p.

Notoya, M., Kihuchi, N., Matsuo, M., Aruga, Y. and Miura, A. 1993. Culture studies of four species of *Porphyra* (Rhodophyta) from Japan. Nippon Suisan Gakkaishi 59: 431-436.

Notoya, M. and Kim N.-G. 1996. Influence of temperature on the formation of a denticulate margin in the foliose thallus of *Porphyra okamurae* Ueda, *P. suborbiculata* Kjellman f. *suborbiculata* Tanaka and *P. suborbiculata* Kjellman f. *latifolia* Tanaka (Bangiales, Rhodophyta). Abstracts of the second Japan-Korea Joint Meeting and Symposium on Aquaculture: 165-166.

Notoya, M. 1997. Diversity of life history in the genus *Porphyra*. *In*: Miyata, M. and Notoya, M. (Eds.), Present and future on biology of *Porphyra* Nat. Hist. Res., Special issue No.3: 47-56.

Ogawa, H. and Lewmanomont, K. 1978. The *Porphyra* of Thailand- I. Morphological characters and spores development of *Porphyra vietnamensis* Tanaka et P-H. Ho. Jap. J. Phycol. 26: 31-34.

Ogawa, H. and Lewmanomont, K. 1979. The *Porphyra* of Thailand-II. Distribution and seasonal occurrence of *Porphyra vietnamensis* Tanaka et P-H. Ho. Jap. J. Phycol. 27: 95-98.

Ogawa, H. and Lewmanomont, K. 1984. The *Porphyra* of Thailand- III. A new record of *Porpohyra vietnamensis* Tanaka et P-H. Ho. and morphological observations on the specimen of *Porphyra* sp. collected from Surin Islands, Andaman Sea. Jap. J. Phycol. 32: 158-161.

Ohno, M. and Largo, D.B. 1998. The seaweed resources of Japan. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency: 1-14.

Oohusa, T. 1993. The cultivation of *Porphyra* 'Nori'. *In*: Ohno, M. and Critchley, A.T. (Eds.), Seaweed cultivation and marine ranching, Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 57-73.

Provasoli, L. 1968. Media and prospects for the cultivation of marine algae. *In*: Watanabe, A. and Hattori, A. (Eds.), Cultures and collections of algae. Proc. U.S.-Japan Conf. Hakone, September 1966. Jap. Soc. Plant Physiol: 63-75.

Rao, M.U. 1969. The seaweed potential of the seas around India. The proceedings of the Symposium on Living Resources of the Seas Around India: 687-693.

Rao, M. U. and Sreeramulu, T. 1970. An annotated list of the marine algae of Visakhapatanam (India) Bot. J. Linn. Soc.63: 23-45.

Segawa, S. 1956. Colored illustrations of the seaweeds of Japan. 8th printing. 1996. Published by Hoikusha Publishing Co.

Soe-Htun, U. and Zaw-Zaw-Pe, U. 1986. Study on the cultivation of conchocelis filaments in *Porphyra crispata* Kjellman. Proceedings of the Burma Research Congress: 7 pp.

Soe-Htun, U. 1998. The seaweed resources of Myanmar. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 99-105.

Sohn, C.H. 1998. The seaweed resources of Korea. *In*: Critchley, A.T and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 15-33.

Suto, S. 1963. Intergenetic and interspecific crossing of the lavers (*Porphyra*). Bull. Jap. Soc. Sci. Fish. 29: 739-748.

Suto, S. 1972. Variation in species characters of *Porphyra* under culture condition. Contributions to the systematics of benthic marine algae of the North Pacific: 193-202.

Tanaka, T. 1952. The systematic study of the Japanese Protoflorideae. Mem. Fac. Fish. Kagoshima Univ., 2(2): 1-92, pls.1-23.

Tanaka, T. and Phang-Hoang Ho 1962. Notes on some marine algae from Viet-Nam-I. Mem. Fac. Fish. Kagoshima Univ., Vol. II, No.1: 3 4-36.

Trono, G.C. Jr. 1977. Guide to Philippine flora and fauna. Seaweeds Vol. I. Economically important seaweed. Department of Natural Resources: 75 pp.

Trono, G. C. Jr. 1998. The seaweed resources of the Philippines. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed

resources of the world Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 47-61.

Tseng, C.K. 1983. Common seaweeds of China. Science Press, Beijing. 316 pp.

Untawale, A.G., Dhargalkar, V.K. and Agadi, V.V. 1983. A check list of Indian marine algae from India. National Institute of Oceanography (NIO), Tech.Rep: 42 pp.

Wang, J-C. and Chiang, Y-M. 1977. Notes on the marine algae of Taiwan II. The genus of *Porphyra*. Taiwania, Vol. 22: 105- 112.

Wu, C. 1998. The seaweed resources of China. *In*: Critchley, A.T. and Ohno, M. (Eds.), Seaweed resources of the world. Kanagawa International Fisheries Training Center. Japan International Cooperation Agency (JICA): 34-46.

Yoshida, T., Nakajima, Y. and Nakata, Y. 1985. Preliminary check-list of marine benthic algae of Japan- I. Chlorophyceae and Phaeophyceae. Jap. J. Phycol. 33: 57-74.

Yoshida, T., Nakajima, Y. and Nakata, Y. 1990. Check-list of marine algae of Japan (revised in 1990). Jap. J. Phycol. 38: 269-320.

Yoshida, T., Nakajima, Y. and Nakata, Y. 1995. Check-list of marine algae of Japan (revised in 1995). Jap. J. Phycol. (S_rui) 43: 115-171.

Yoshida, T. 1997. The history and future prospects of systematics of Bangiaceae, Rhodophyta. *In*: Miyata, M. and Notoya, M. (Eds.), Present and future on biology of *Porphyra*. Nat. Hist. Res., Special issue No.3: 1-4.

Yoshida, T., Notoya, M., Kikuchi, N. and Miyata, M. 1997. Catalogue of species of *Porphyra* in the world, with special reference to the type locality and bibliography. *In*: Miyata, M. and Notoya, M. (Eds.), Present and future on biology of *Porphyra*. Nat. Hist. Res., Special issue No.3: 5-18.