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Studies on morphological variations in *Sargassum cristaefolium* C. AGARDH (Phaeophyta, Fucales)

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The developmental process of *Sargassum cristaefolium* C. AGARDH is described to study morphological variations in vegetative and reproductive features. Morphological variations of branches, leaves and vesicles depend on ages and habitats of the plants. Gradual changes in morphology of these three features are numbered arbitrarily to know the lowest and highest limits of development in the plants growing in shallow and deep water at different ages. Receptacles of shallow and deep water plants are nearly uniform in morphology.

Key Index Words: *Fucales*; *morphology*; *Phaeophyta*; *Sargassaceae*; Sargassum; S. cristaefolium; *variations*.

A wide range of phenotypic morphological variations shown by many species of *Sargassum* caused much difficulties in identifying the plants as to species or understanding of variability in the same species. Our observations on development of the thallus in several species occurring in the Indo-Pacific regions suggest that there is certain regularity in morphological changes of branches, leaves and vesicles according to ages or developmental stages and habitats of the plants. We present here, as an example, our observations on *Sargassum cristaefolium*, first described by C. AGARDH in 1820 based on the specimen from Ceylon (Sri Lanka), and known from tropical Pacific areas as well as Indian Ocean regions. Similar observations on each taxon are indispensable to go further in understanding the taxonomy of this genus of Phaeophyta.

Materials and Methods

The materials were collected from various localities, such as Guam Island, Micronesia and Kagoshima Prefecture, Japan at ecologically different habitats throughout the growing season. Specimens were preserved in 10% formalin in seawater and also mounted on herbarium sheets. Herbarium sheets examined were deposited in the herbarium of Faculty of Science, Hokkaido University (SAP). Liquid-preserved specimens of whole plants were used for observations of external morphology and habits of vegetative and reproductive features. The terms used here were in accordance with those of YOSHIDA (1983). Stems, branches, leaves, vesicles and receptacles were studied from lower to upper parts according to their positions on plants. Sections were made by hand using a double-edge razor blade for the study of reproductive organs.

Observations

S. cristaefolium (Fig. 1) is normally an annual plant. Plants attach to rocks and coral reefs by a discoidal holdfast from the lower intertidal zone in shallow rock and tidal

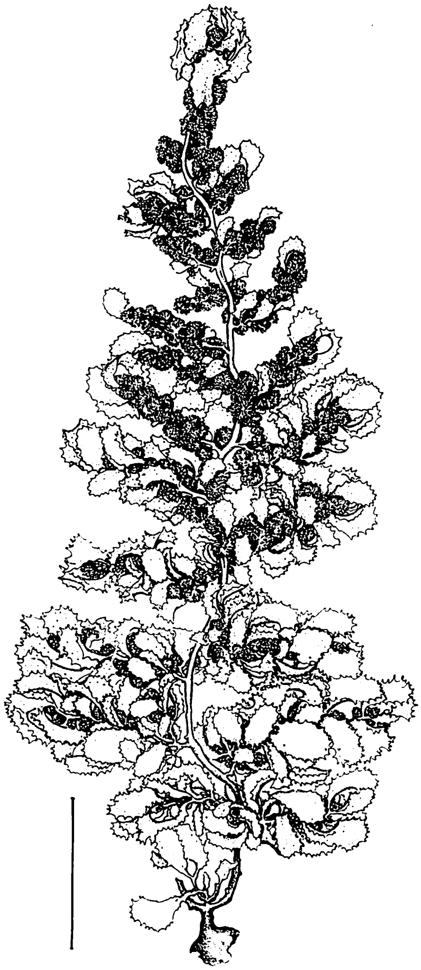

Fig. 1. *Sargassum cristaefolium* C. AGARDH. Pago Bay, Guam I. June 18, 1984. leg. T. YOSHIDA. Scale, 5 cm.

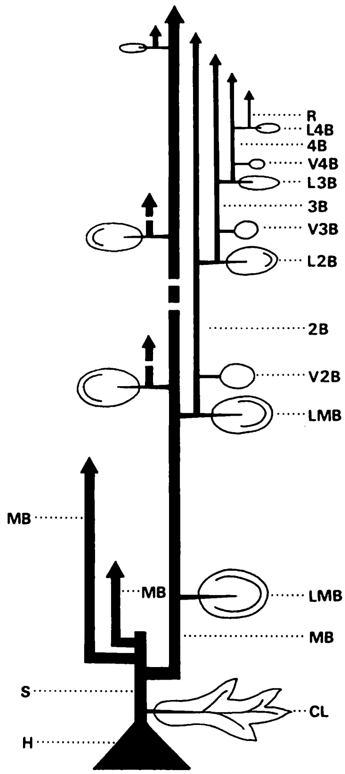

Fig. 2. Developmental process in *Sargassum cristaefolium*. H, holdfast; CL, cauline leaf; S, stem; MB, main branch; LMB, leaf of main branch; 2B, second branch; L2B, leaf of secondary branch; V2B, vesicle of secondary branch; 3B, tertiary branch; L3B, leaf of tertiary branch; V3B, vesicle of tertiary branch; 4B, fourth order branch; L4B, leaf of fourth order branch; V4B, vesicle of fourth order branch; R, receptacle.

pools to the subtidal zone, about 2 m deep. Young plants appear in autumn and become mature in next spring to summer. The stem is less than 1 cm in length and 2-4 mm in diameter, usually without branching. The length of main branches of shallow water plants, measuring 10-20 cm, is shorter than that of deep water plants, measuring 20-40 cm. In some cases, the shortest length of main branches, measuring 5-10 cm is found in plants which are exposed to air during the ebb tide.

The developmental process of *S. cristaefolium* is schematically shown in Fig. 2. In younger stages, several furcate cauline leaves without margical duplications are formed in the early season of growth. Subsequently, main branches are issued in spiral order from lower to upper parts of the stem. After the development of main branches, cauline leaves fall off. Main branches on the stem become longer, although those on the upper part of the stem remain short in length. One to five leaves in the proximal parts of the branches do not issue the branches of next order. From lower middle to middle parts of main branches, secondary branches are issued in the axils of leaves of main branches with vesicles and leaves of secondary branches, then tertiary branches, vesicles and leaves of tertiary branches, branches of fourth order, vesicles and leaves of fourth order and receptacles successively. However, in the upper parts of main branches, younger secondary branches with its small vesicles and leaves are formed, usually without further development of next order branches. Vesicles are totally absent on main branches. Vesicles are also absent on secondary branches arising from lower parts of main branches. One or two vesicles replace the leaves formed at the proximal parts of secondary and higher order branches. As far as we have examined, well grown individuals have branches of fourth order in deep water habitats. These plants denude leaves of main branches from lower to middle parts of main branches after initiation of axillary branches. However, leaves of main branches mostly remain in the distal parts.

Width of main branches is always two times larger than that of secondary branches according to their positions on plants. The same relations are found between secondary and tertiary branches, and so on. Likewise, size diminution occurs in leaves and vesicles of branches concerned. At the end of growing season, fifth order branches in the lower parts of fourth order branches and fourth order branches in the lower parts of tertiary branches are normally transformed into receptacles in deep water plants, but fourth order and tertiary branches can be changed into receptacles in shallow water and exposed plants. Receptacles are nearly uniform as for size and furcation even in the plants growing in different habitats. These are always androgynous irrespective of plant size and habitats.

Grades of development of branches, leaves and vesicles are arbitrarily classified into five steps (Fig. 3). Grade 4 means the highest limit of variations or maximum state of development and grade 0 represents the lowest limit of variations or minimum state of development for these three parts of the plants. Between grades 4 and 0, grades 3, 2 and 1 indicate gradation of morphological development. Whole range of variations is found along main branch (grades 4-0), while on secondary branch lesser range is seen (grades 3-0). Similarly, tertiary (grade 2-0) and fourth order (grades 1-0) branches have narrower range of variations according to their positions on plants. Such a tendency in gradual changes of morphological characters also occurs in leaves and vesicles depending on ages of plant and its habitats.

The highest limit of variations or maximum developmental grade of main branch development is always observed at the proximal parts of early formed main branches from younger to older stages of the plants collected from every habitat. However, as for leaves and vesicles, developmental grade 3 is firstly formed in younger stages of plants. Later, as the plants are getting older, these grades 3 in leaves and vesicles gradually develop into the highest grade of variations (i. e. grade 4). These gradual developmental changes normally occur in individual leaf and vesicle as affected by ages and ecological conditions. The extent of these changes in each leaf and vesicle are more eminently observed than in the proximal parts of main branches.

As shown in Fig. 3A, proximal parts of main branches, which are issued from the lower parts of the stem, are ancipital (i. e. grade 4) but lower middle to upper part of main branches are usually compressed to terete without ridges (i. e. grades 3-0). However, according to the relative position on the stem, proximal parts of later issued main branches become compressed without ridges (i. e. grades 3-0). Simultaneously, gradual changes of morphology (i. e. grades 3-0) are also found on secondary, tertiary and fourth order branches from lower to upper parts of plants. In this case, secondary and tertiary branches are mostly compressed but fourth order branches are usually terete. Issuing of secondary, ter-

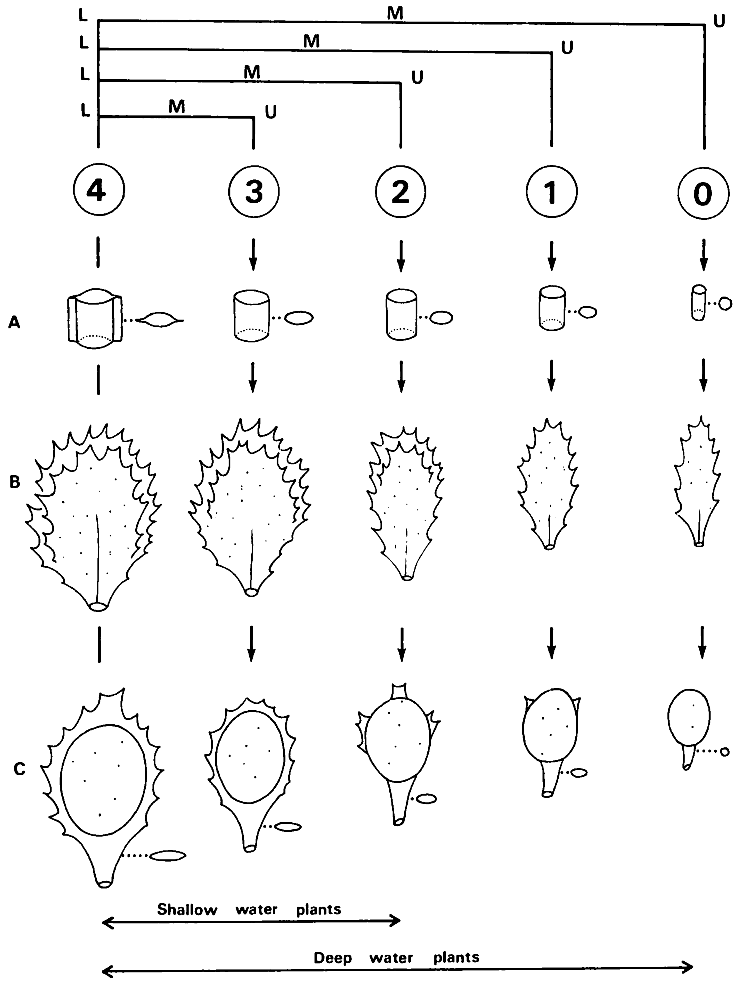

Fig. 3. Gradual changes of morphology in *Sargassum cristaefolium*. Grades (4-0). L, lower; M, middle; U, upper.

tiary and fourth order branches are affected by their life time and environmental factors. Moreover, even in a single plant, fewer branches of higher order are produced on main branches which are issued later than those formed in earlier season.

Heterophylly observed is shown in Fig. 3B. Leaves in the lower parts of main branches are thick, concave at the surface and strongly curved upwards, bifariously dentate and spatulate to oblong in shape with marginal duplications starting from lower middle portions of blades on each side. This state is called here as grade 4 while those on the upper parts of main branches become smaller and thinner, irregularly serrate and oblong to lanceolate in shape without marginal duplications (i. e. grades 1-0). Gradual changes of leaf morphology (grades 3-0) are also found on leaves of secondary, tertiary and fourth order branches. Morphological variations of leaves in shallow water plants (i. e. grades 4-2) have lesser range than those of deep water plants (i. e. grades 4-0).

Interval of leaf formation or the length of internode depends on depths where the plants grow. The length of the internode is usually shorter in plants of shallow water or exposed habitats while relatively longer in deep water plants. Distinction of midrib in leaves depends on ages of plants. The midrib reaches to the middle portion of blade in older leaves but only to the lower part of blade in younger leaves.

Fig. 3C represents the morphological range of vesicles. Vesicles of secondary branches formed in the lower middle parts of main branches are bigger and usually have small lateral appendages (i. e. grade 4) but those of secondary branches disposed in the upper parts of main branches become smaller in size and have no lateral appendage (i. e. grade 0). Apices of well grown vesicles are slightly mucronate but vesicles of grade 0 are always mutic at the apex. And also, stipes of the higher grade vesicles are mostly flattened but those of the lower grades are normally compressed to terete. Similar gradual changes of morphology (i. e. grades 3-0) occur on vesicles of tertiary and fourth order branches.

The main characteristics of *S. cristaefolium* can be summarized as follows:

(1) Main branches are slightly flattened to compressed with or without ridges at the basal parts, 10-40 cm in length and 2-4 mm in width.

(2) Leaves are spatulate, oblong to lanceolate in shape, 10-20 mm in length, 10-20 mm in width, mostly concave at the surface and strongly curved upwards, duplicate to simple, shortly stipitate with symmetrical base, evanescent midrib vanishing at the middle way to the apex, bifariously dentate to irregularly serrate margins and obtuse to acute apex.

(3) Vesicles are mostly elliptical in shape with or without small appendages, 3-10 mm in diameter with slightly mucronate or rounded tips and flattened, compressed to terete stipes of 1/2-1/3 length of vesicles.

(4) Receptacles are androgynous, cymosely arranged, compressed, loosely twisted with small spines, irregularly forked, 5-10 mm in length and 0.5-1.0 mm in width with a short sterile stipe.

Discussion

The developmental process of the plant body (thallus) in *S. cristaefolium* is fundamentally similar to that of *S. piluliferum* (TURNER) C. AGARDH, *S. patens* C. AGARDH, *S. duplicatum* J. AGARDH, *S. cristpifolium* YAMADA and *S. asymmetricum* YAMADA reported by TERAWAKI *et al.* (1982, 1983a, b, c, 1984). At early stages of development of germlings, simple cauline leaves are formed and then furcate cauline leaves appear in all these species. Later, main branches replace the cauline leaves at certain stage of development. The phenomenon of apical dominance, as mentioned by CHAMBERLAIN *et al.* (1979) for *S. muticum* (YENDO) FENSHOLT, may control the development of next order branches. In other words, the upper limits of morphological development of branches, leaves and vesicles are closely related with the position of each part of the plants. Growth in length of branches, also depends on habitat conditions.

In shallow or rough water habitats, the plants have shorter main branches, giving rise to poorly developed short secondary and tertiary branches. Maximum to minimum grades of development of each part cannot be easily seen in these plants. In deep or calm water habitats, main branches grow generally longer and give rise to longer secondary and tertiary branches often provided with short fourth order branches. Leaves of the lower parts of main branches are quite different from those of the upper parts in morphology. All grades of gradual changes in leaf morphology are observed. That is to say, heterophylly is more conspicuous. On the other hand, leaves of fourth order branches are quite similar in shape to leaves of fifth order branches. A narrower range of leaf morphology is noticed on the branches of higher orders. The same phenomena are also found in branch and vesicle characteristics.

Based on these observations, ranges of gradual changes of morphology in branches, leaves and vesicles are diagrammatically

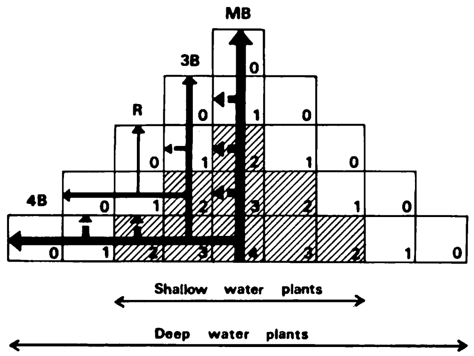

Fig. 4. Scheme of gradual changes of morphology in *Sargassum cristaefolium*. Hatched area shows shallow water plants. Grades in numerals 4–0. MB, main branch; 2B, secondary branch; 3B, tertiary branch; 4B, fourth order branch; R, receptacle.

expressed in Fig. 4. For instance, in well grown deep water plants, highest limit of variations or maximum developmental grade (i. e. grade 4) can be seen in the proximal parts of main branches which are issued earlier in growth season. The lowest limit of variation or minimum developmental grade (i. e. grade 0) is found in the distal parts of main, secondary, tertiary and fourth order branches. Grade 3 is formed in the lower middle of main and lower parts of secondary branches. Intermediate grade 2 occurs in the middle parts of main, lower middle parts of secondary and lower parts of tertiary branches. Similarly, grade 1 can be found in the upper parts of main, secondary, middle portions of tertiary and lower parts of fourth order branches. However, in plants grown in shallow water, range of developmental grades (i. e. grades 4–2) is less than that (i. e. grades 4–0) of deep water plants. In general, variation of deep water plants with older main branches exhibits widest range of developmental grades.

In some cases, it is very difficult to obtain complete specimens. And also, maximum developmental grade cannot be observed at the end of growing season because the first formed leaves on main branches have fallen off during the growth. The gradation of developmental stages from grades 0 to 4 must be clearly recognized as for branches, leaves and vesicles as well as their relation with habitats. For each species, the whole range of morphological variations must be known and recorded from various geographical areas of its distribution in understanding a species limit. Without this process, circumscription of taxa remains always insufficient and comparison of population from different geographical areas would be incomplete. Hence, the advance of taxonomic knowledge cannot be expected.

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ウ スートン*・吉田忠生: 褐藻トサカモク *Sargassum cristaefolium* の形態変異について**

トサカモク *Sargassum cristaefolium* C. AGARDH の個体発生の過程を栄養体と生殖器官の発達について記述した。枝，葉，気胞の形態的な変異の範囲は個体の齢と生育場所によって定まる。これら体の3部分のそれぞれについて形態の単純なものからよく発達したものまで5段階に分け，生育場所や発育段階によってどの段階の形質を示すかを明らかにした。生殖器床は比較的変異が少ない。(* Department of Marine Sciences, Moulmein University, Moulmein, Burma ** 060 札幌市北区北十条西8丁目 北海道大学理学部植物学教室)

Change of Office and Editor

The new Editor of the Japanese Journal of Phycology for 1987-1988 is Yoshihiro Tsubo of Kobe University. Starting in January 1987, manuscripts for publication should be submitted directly to the Editor, **Prof. Y. Tsubo, Department of Biology, College of Liberal Arts, Kobe University, Nada, Kobe, 657 Japan.**

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