Taxonomic Study of Six *Sargassum* Species (Sargassaceae, Fucales) with Compressed Primary Branches in the Persian Gulf and Oman Sea Including *S. binderi* Sonder a New Record Species for Algal Flora, Iran

M. Shams*, S. Afsharzadeh, and Gh. Balali

*Department of Biology, Faculty of Science, University of Isfahan, Isfahan, Islamic Republic of Iran*

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**Abstract**

Six species of *Sargassum* C. Agardh (Sargassaceae) with compressed primary branches, including: *S. binderi* Sonder, *S. aquifolium* (Turner) C. Agardh, *S. oligocystum* Montagne, *S. swartzii* (Turner) C. Agardh, *S. crassifolium* J. Agardh and *S. cristaefolium* C. A. Agardh, were identified in the Persian Gulf and Oman Sea coasts, among which *S. binderi* is reported as newly recorded species in Iran for the first time. The specimens were collected from 15 stations along the Iranian southern shores in the autumn, winter and spring from 2010 to 2012. Anatomical and morphological studies were performed according to the valid identification keys. In taxonomy studies, 47 quantitative and qualitative morphological characters were selected. In order to analyze of data, clustering analysis was performed by UPGMA and PCA analyses. The results revealed that there were more qualitative than quantitative traits in species identification. The shape of receptacles, leaves, vesicles and stems were the most diagnostic characteristics in the species identification. The species including: *S. binderi*, *S. crassifolium* and *S. cristaefolium* have flattened triangular receptacles; while *S. crassifolium* and *S. cristaefolium* have duplicated leaves with fine teeth; *S. swartzii* has linear lanceolate leaves, pointed or crowned vesicles and *S. oligocystum* has broader lanceolate leaves with an acute to rounded apex, and often entire and spherical vesicles. *S. oligocystum* and *S. crassifolium* belong to the section *Acanthocarpicae*. Also, *S. cristaefolium* belongs to section *Sargassum* and *S. binderi*, *S. aquifolium* and *S. swartzii* belong to section *Binderianeae*.

**Keywords:** *Sargassum*; Persian Gulf and Oman Sea; Phaeophyta; Compressed branches; Iran.

**Introduction**

*Sargassum* C. Agardh represents the most species rich genus of marine macroalgae in tropical regions [1] and morphologically, it is among the most complex phaeophyceaen genera. Some species are economically

* Corresponding author: Tel: +9809132322940; Fax: +9803142324420; Email: Shamsshiva80@gmail.com
important, especially in Asian countries where they are commonly used as food (soup and salad), liquid fertilizer and animal feeds. In addition, fucoidans extracted from the cell wall were discovered to have antitumor [2] and cytotoxic activities [3]. Here we focus on the six species of Sargassum with compressed primary branches in the Persian Gulf and Oman Sea. The Persian Gulf is a shallow sea, which experiences very high annual variation in seawater temperature. These extreme physical conditions impose stress on the scleractinian corals [4], which results in severe competition for space and light with Sargassum. Despite their ecological importance there have been studies focusing on the morphological and alginate extraction of Sargassum in the Persian Gulf and Oman Sea [5, 6, 7]. This can at least partly be attributed to the complex systematics of the genus, which is characterized by considerable morphological plasticity and the hundreds of species and intraspecific names which have been used [8]. Previous phycological studies in Persian Gulf were compiled by several authors [6, 7, 8, 9], and more ecologically oriented research was conducted by Sheppard et al. (1992) [4]. In addition, Sohrabipour & Rabii (1999) have identified 6 Sargassum species in this area [10]; while Gharanjik (2005) reported five Sargassum species in Sistan and Baluchestan coasts (Oman sea) in the southeast of Iran [11]. Recently, Shams et al. (2013) reported 19 Sargassum species in Persian Gulf and Oman Sea [12]. In this paper, we described six Sargassum species with compressed primary branches, including: S. binderi Sonder, S. aquifolium (Turner) C. Agardh, S. oligocystum Montagne, S. swartzii (Turner) C. Agardh, S. crassifolium J. Agardh and S. cristaeofoili C. A. Agardh and their clear distinguishable characters.

Materials and Methods

The specimens were collected from 15 localities ranging from Sistan and Baluchestan Province (between 25° 03’ and 31° 28’ N; between 58° 47’ and 63° 19’ E) to Bushehr Province (between 28°52’ N and 50°44’ E) along the Iranian shores of the Persian Gulf and Oman Sea from December (2010-2012), January (2010, 2011) and May (2010-2012) (Fig. 1, Table. 1). The complete thalli were collected from reef flats at low tide from a variety of habitats down to 3 m depth. The specimens were fixed in 4% formaldehyde, and the remainder was dried on herbarium sheets. The morphological characters used for analysis includes thallus length, holdfast and stem shape, primary and secondary branches, leaf length, width and shape at the apex, base and margin, vesicle length, width, pedicle and receptacle shape. Also, transverse sections of receptacles were prepared and stained using 1% aniline blue, intensified with 1% HCl. Specimens were studied using a Stemi 2000-C Zeiss stereo microscope and photographed by Canon Power shot G6 camera.

Figure 1. Study area and localities of collection for Sargassum along the Persian Gulf and Oman Sea seashore of Iran. Black circles show studied collected sites.
Identification was carried out based on the some taxonomic references [5, 6, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28 and 29]. In addition, in this study, the species were checked with available specimens of Belgium, Mexico, Australia, Indian Ocean and Japan in Ghent herbarium. It is noticeable that, the most of these syntypes previously had been checked with origin Holotype. Finally, all of the species nomenclatures were checked with AlgaeBase site. Iranian *Sargassum* species are deposited at the Herbarium of the University of Isfahan (HUI).

**Results**

All of the *Sargassum* species commonly grow on rocks and dead corals in littoral and sub-littoral sites. *Sargassum* species were collected from different sites along the Iranian southern coasts, identified, checked for synonymy accepted names with www.algaebase.org site and referred to its systematic groups. *Sargassum* density was much higher in Sistan and Baluchestan Province and Bandar Lengeh Lengeh Province than other sites. In total, in taxonomical study regarding to 47 quantitative and qualitative morphological characters as shape and size of leaves, stem, receptacles and vesicles shape and size; six species belong to three Sections including of *Binderianae*, *Ilicifoliae* and *Acanthocarpicae* were identified. An identification key to the *Sargassum* species with compressed primary branches of Iran is presented in the below.

**Identification key for the Iranian Sargassum species with compressed primary branches**

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Collected Stations</th>
<th>Collected Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. oligocystum</em> (N29, L57, N25, L52)</td>
<td>Bandar Lengeh, Qeshm Island, Bushehr</td>
<td>December 2011, May 2012</td>
</tr>
<tr>
<td><em>S. crassifolium</em> (GH5, Q10, Q15, Q13, N20, LS16)</td>
<td>Sistan and Baluchestan Province, Bandar Lengeh, Qeshm Island</td>
<td>May and December 2010-2011</td>
</tr>
<tr>
<td><em>S. binderi</em> (NL20, NL22, NL23, NL25, NL204, LS207, N7)</td>
<td>Bandar Lengeh Province, Qeshm Island</td>
<td>January 2010-2011, December 2012</td>
</tr>
<tr>
<td><em>S. aquifolium</em> (N14, N15, N16, LS6, N12, NL205, LS23, LS5, LS4, N2)</td>
<td>Bandar Lengeh Province, Bushehr, Qeshm Island</td>
<td>January 2010, May 2012</td>
</tr>
</tbody>
</table>

3- Vesicles pointed, often crowned with mucronate at the apices, flattened stalk, receptacles flattened, often twisted……………………………..*S. binderi*

4- Leaves deeply dentate, spatulate, margin possibly double, cryptostomata large……………………………………5

5- Vesicles obovate and often not mucronate………………..*S. oligocystum*

*Species of* *Sargassum* species and their collected sites in the Persian Gulf and Oman Sea.

*Sargassum aquifolium* (Turner) C. Agardh [14, 15, 16, 22, 25, 27, 30].

**Holotype:** *S. bacciferum* (Turner) C. Agardh

**Classification species:** Subgenus *Sargassum*, Section *Binderianae*

Holdfast discoid, up to 8 mm in diameter. Stem terete, smooth or warty, up to 2.5 mm in diameter and 1 cm long. Primary branches flattened to compressed, smooth, up to 35 cm long and 1.8 mm in diameter; leaves large, lanceolate, simple, with asymmetrical bases, up to 4.5 cm long and 1.5 cm width, with rounded to acute apices, margins dentate with small teeth, midribs distinct near apices or vanishing midway; small cryptostomata are scattered in to rows on both sides of the midrib. Secondary branches spirally arranged, compressed, smooth, up to 35 cm long. Leaves lanceolate to linear; simple with asymmetrical bases; up to 5 cm long and 1.5 cm width; with rounded apices; dentate margins with sharp teeth. Vesicles spherical, sometimes elliptical, up to 18 mm long, 3.2 mm width, stalks terete, usually shorter than the vesicles (Fig. 2). Plants monococious. Receptacles androgynous, flattened, often twisted, up to 1.6 cm long and 2 mm width, sharply dentate at the margin, simple to once to twice furcate. Receptacles arranged racemously and
acanthozygocarpi. However, there was not any receptacle in Iranian species.

**Habitat:** Coral flats and subtidal zone.

**Ecology:** This species usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It was found only in Qeshm Island and Bandar Lengeh Province.

*Sargassum binderi* Sonder [14, 15, 16, 19, 20, 22, 25, 27, 30].

**Holotype:** *S. bacciferum* (Turner) C. Agardh

**Classification species:** Subgenus *Sargassum*, Section *Binderianae*

Holdfast discoid; up to 10 mm in diameter. Stem terete, smooth or warty; up to 2.5 mm in diameter and 1 cm long. Primary branches flattened to compressed, smooth, up to 40 cm long and 3 mm in diameter; leaves large, lanceolate, simple, with asymmetrical bases, up to 5.5 cm long and 1.5 cm width, with rounded to acute apices, margins entire to dentate with small teeth, midribs distinct near apices or vanishing midway, small cryptostomata are scattered in to rows on both sides of the midrib. Secondary branches spirally arranged, compressed, smooth, up to 40 cm long. Leaves lanceolate to linear; simple with asymmetrical bases; up to 5.5 cm long and 1.5 cm width; with rounded apices; margins dentate with sharp teeth. Vesicles spherical; sometimes elliptical, up to 20 mm long, and 4 mm width, often mucronate at the apices, sometimes entire, stalks flattened, usually longer than the vesicles (Fig. 3).

Plants monoecious. Receptacles androgynous, flattened, often twisted, up to 1.6 cm long and 2 mm width, sharply dentate at the margin, simple to once to twice furcate. Receptacles arranged racemously and zygocarpicea.

![Figure 2. Sargassum aquifolium (Turner) C. Agardh a) Habit, b) leaves, c) vesicles. Scal bar: a= 5 cm, b, c = 5 mm](image)

![Figure 3. Sargassum binderi Sonder. a) Habit, b) leaves, c) vesicles, d) receptacles, e) transverse section of receptacle. Scal bar a= 5 cm, b, c, d = 5 mm](image)
Habitat: Coral flats and subtidal zone.

Ecology: This is a new record species from Iran, usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It was found only in Qeshm Island and Bandar Lengeh Province.

*Sargassum crassifolium J. G. Agardh [14, 15, 16, 19, 20, 22, 25, 27, 30].
Holotype: S. bacciferum (Turner) C. Agardh.
Synonyms: S. aquifolium (Turner) C. Agardh
Classification species: Subgenus Sargassum, Section Acanthocarpicae

Thalli up to 85 cm high with discoid holdfast; up to 9 mm in diameter. Main and primary branches terete, smooth, up to 4 mm in diameter, 45 mm long. Leaves of the main branches coriaceous, lanceolate to oblong-lanceolate, up to 30 long and up to 12 mm width, usually with rounded and double serrulate apices, margins dentate, midribs vanishing midway to distinct near apices, cryptostomata scattered or arranged in rows. Leaves on the primary branches coriaceous, with lanceolate-oblong-lanceolate to lanceolate-oblong-lanceolate, up to 25 mm long and up to 8 mm width. Midrib percurrent and distinct; margin duplicated; apex obtuse (Fig. 4). Cryptostomata are scattered or arranged in rows. Vesicles phyllocystic; up to 6 mm in diameter, bearing cryptostomata on the vesicles. Phylllocysts provided with marginal appendages or wings; stalks with lower part terete and upper part compressed to folicaceous, usually shorter or sometimes longer or equal to the vesicles; S. crassifolium is widely distributed and recognized by its duplicated margin and phyllocystic vesicles. Iranian specimens showed great resemble to those of Philippines and Thailand.

Plants monoecious. Receptacles terete in lower part and slightly compressed in upper part, up to 15 mm long and 1.2 mm width, simple to furcated up to four times, with a warty surface, bearing spines at the apex, arranged in a cymose to compound cymose, pseudozygocarpic.

Habitat: Coral flats and subtidal zone.

Ecology: This species usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It was found only in Qeshm Island and Bandar Lengeh Province.

*Sargassum cristaefolium C. A. Agardh [14, 15, 16, 22, 25, 27, 30].
Holotype: S. bacciferum (Turner) C. Agardh
Synonyms: S. ilicifolium (Turner) C. Agardh
Classification species: Subgenus Sargassum, Section Sargassum

Thalli up to 90 cm high with discoid holdfast. Main and primary branches terete and smooth. cryptostomata are present on the main branches. Leaves of the main branches coriaceous, broad oblong-lanceolate to ovate-obovate, up to 18 mm long and up to 6 mm broad. Midrib distinct and running halfway along the length of the leaf; margin duplicated. Apex obtuse. Cryptostomata randomly distributed. Leaves on the primary branches coriaceous, ovate to obovate, up to 12 mm long and up to 5 mm broad. Midrib distinct and running halfway along the length of the leaf; margin duplicated. Apex obtuse. Cryptostomata scattered. Vesicles are spherical; up to 1 mm in diameter; apex obtuse and pedicel short.

Figure 4. Sargassum crassifolium J. G. Agardh. a) Habit, b) leaves, c) vesicles, d) receptacles, e) transverse section of receptacle. Scal bar a= 5 cm, b, c, d = 5 mm.
The cryptostomata are present on the vesicles (Fig. 5). Plants monoecious. Receptacles terete in lower and slightly compressed in upper parts, up to 10 mm long and 8 mm width, simple to furcated up to four times, bearing spines at the apex, arranged in a cymose, pseudozygocarpic. Receptacles were not observed in the Iranian species, but according to others characters, these species showed great resemblance to those of Philippines and Malaysian.

**Habitat:** Coral flats and subtidal zone.

**Ecology:** This species usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It has been found only in Qeshm Island and Bandar Lengeh Province.

*Sargassum oligocystum* Montagne [14, 15, 16, 19, 20, 22, 25, 27, 30].

**Holotype:** *S. bacciferum* (Turner) C. Agardh.

**Synonym:** *Carpacanthus oligocystum* (Montagne) Kützing

**Classification species:** Subgenus *Sargassum*, Section *Acanthocarpicae*

Thalli up to 100 cm high with discoid to scutitate holdfast, up to 8 mm in diameter. Main and primary branches flattened to compressed, smooth, up to 43 cm long and 3 mm width. Leaves of the main branches membranous, lanceolate to spatulate, up to 41 mm long and up to 6 mm broad, with rounded apices, margins entire to dentate with small teeth, midribs vanishing to distinct near apices, small cryptostomata scattered. Leaves on the primary branches membranous, lanceolate, up to 38 mm long and up to 3.4 mm width. Midrib percurrent and distinct; margin sharply dentate, apex acute or obtuse, and cryptostomata scattered. Vesicles spherical or elliptical, up to 2.6 mm in
diameter. Apex obtuse; rarely mucronate, stalks terete, usually shorter than the vesicles, bearing of cryptostomata on the vesicles. Some specimen had broader and longer leaves compared to others (Fig. 6). In addition, the vesicles of Qeshm Island were smaller and seldom exceeded 3 mm in diameter. In contrast, the vesicles of Bandar Lengeh species were around 4 mm in diameter. Plants monoecious. Receptacles androgynous, slightly compressed, up to 7 mm long and 3 mm width, warty or with a few marginal spines; simple to two or three times furcated, racemously arranged, pseudozygocarpic.

Habitat: Coral flats and subtidal zone.

Ecology: This species usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It has been found only in Qeshm Island, Bushehr and Bandar Lengeh Province.

*Sargassum swartzii C. Agardh [14, 15, 16, 19, 20, 22, 25, 27, 30].

Holotype: S. bacciferum (Turner) C. Agardh.

Synonyms: Fucus swartzii Turner; S. spathulaefolium J. Agardh; S. wightii Greville ex J. Agardh; S. acutifolium Greville.

Classification species: Subgenus Sargassum, Section Binderianae

Thalli up to 86 cm high with discoid holdfast, up to 12 mm in diameter. Main and primary branches compressed and smooth. Leaves of the main branches coriaceous, linear lanceolate to linear oblanceolate, up to 26 long and up to 4 mm broad. Midrib distinct and percurrent; margin entire to occasionally tooth; apex acute or obtuse. Cryptostomata in rows; leaves of the primary branches coriaceous, linear lanceolate to linear oblanceolate, up to 25 long and up to 3 mm broad, midribs distinct near apices, cryptostomata small and scattered. Margin entire to occasionally tooth; apex acute or obtuse, cryptostomata in rows. Vesicles elliptical to fusiform, up to 5 long and 2 mm width; crowned with horn-like spin, apex pointed or with a short leafy crown, margins entire, stalks terete to slightly compressed or terete in the lower and compressed in the upper part, usually shorter than the vesicles or sometimes longer. Cryptostomata present on the vesicles (Fig. 7). Plants monoecious; Receptacles slightly terete, up to 13 mm long and 1.7 mm width, simple to furcated 2–5 times, bearing spines at the apex, arranged in a cymose to compound cymose, pseudozygocarpic.

Habitat: Coral flats and subtidal zone.

Ecology: This species usually grows in the lower portions of the intertidal zone on rock substrates or shallow subtidal zones. It was found only in Qeshm Island and Bandar Lengeh Province.

In total, in the taxonomy studies, 47 quantitative and qualitative morphological characters were selected. The clustering analysis of UPGMA show that these characters can be separated sections well (Fig. 8). S. swartzii, S. aquifolium, S. binderi and S. crassifolium classified together as a distinct clade (Sect. Binderianae), and S. oligocystum belong to Sect. Acanthocarpicae and S. cristaefolium belong to Sect. Illicifolia clustered together in a common clade. In addition, PCA analysis (Fig. 9) separated three sections as morphological characters well.

Discussion

In this study, six species of Sargassum with compressed primary branches including: S. binderi Sonder, S. aquifolium (Turner) C. Agardh, S. oligocystum Montagne, S. swartzii (Turner) C. Agardh,
S. crassifolium J. Agardh and S. cristaefolium C. Agardh, were described from the Persian Gulf and Oman Sea of Iran. S. binderi was a new record species from Iranian coasts. The clear diagnostic traits of these species were clearly presented and discussed in the current study. In this study we observed that the Sargassum population developed in winter (December and January). S. binderi, S. crassifolium and S. cristaefolium have flattened and sometimes triquetrous receptacles while S. crassifolium and S. cristaefolium have duplicated margins. S. swartzii has linear lanceolate leaves, pointed or crowned vesicles. S. oligocystum has broader lanceolate leaves with an acute to rounded apex, almost entire and spherical vesicles. S.
swartzii was reported by Tseng as an androgy nous plant in which both male and female reproductive organs occur in the same receptacles [23]. In the S. swartzii, receptacles were slightly flattened and repeatedly furcated and arranged in cymosely. The Iranian specimens showed great resemblance to those from Vietnam, Malaysian and Thiland. S. swartzii was found in the Sistan and Baluchestan Province, Hormoz and Bushehr Province. Also, S. binderi, S. aquifolium, S. crassifolium and S. cristaefolium were found in Bandar Lengeh and Qeshm Island. The S. oligocystum only was observed in Bushehr Province. S. crassifolium and S. cristaefolium easily was differentiated from each other by leaves duplicated margin. S. binderi has been characterized by the receptacles with sharply spinous margin. Womersley and Bailey [29] suggested that S. binderi was a synonym of S. oligocystum, but this was disputed by Tseng and Lu [25, 26] and Ajisaka et al [16]. According to AlgaeBase, this species currently considered as synonym of S. aquifolium. However, we retain S. binderi on the basis of its characteristic receptacles with a clear spinous margin. Found S. binderi in Iran is closely similar to Thailand and China samples [19, 25] for its vessels and receptacles morphology. S. binderi and S. oligocystum are often misidentified as they share some morphological characters especially in young plant, both species are monoecious. The result of the present study revealed the identical features of S. oligocystum and S. aquifolium. In this survey, S. binderi, S. aquifolium and S. oligocystum had large cryptostomata on their leaves [20, 30]. Silva et al. reported that this species was wrongly named as S. acinaria by some authors [31]. Also, Noro et al. showed that Fucus swartzii Turner is basionym for the S. swartzii (Turner) C. Agardh [21]. In addition, results of UPGMA clustering analysis based on Jaccard's similarity coefficient on the quantitative and qualitative data phenotypic populations of six species separate and classify theirs sections. Of 47 quantitative and qualitative traits, qualitative characters such as branching and leaf tip margins, shape and vesicles and receptacles shape were the best traits for identification. S. crassifolium nested with S. aquifolium in the same clade (in sect. Binderianae); and also, S. cristaefolium clustered under sect. ilicifolii in a separated clade. In the other hand, we confirmed that S. crassifolium should be considered a synonyme of S. aquifolium as Guary and Guary, 2013. PCA analysis regard to diagnostic characters separated phenotypic populations belonging to three sections containing six species as well (Bandar Lengeh and Qeshm Island from Sistan and Baluchestan Province). In conclusion, this study show that the qualities and quantities traits add to anatomical studies can be important in the Sargassum species identification.

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