BEACH-CAST SEAWEEDS FROM ITAQUI BEACH, COAST OF THE STATE OF PIAUÍ, NORTHEAST OF BRAZIL

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ABSTRACT

The phycoflora on the coast of Piauí is still among the least studied in Brazil, especially when it comes to knowledge of the infralittoral. The flora of the infralittoral in Brazil is known mainly for the analysis of material stored on the beaches. Beach-cast seaweeds originate from benthic algal banks, mainly from the infralittoral and occur frequently on many beaches in the northeastern, southeastern, and south of Brazil, during low tide. Studies indicate the great biotechnological potential of algae with possibilities of its use, in the production of phycocolloids, such as human food, animal feed, fertilizers, drugs, among others. However, the beach-cast seaweeds have been treated like garbage, commonly incinerated or collected for landfills. Therefore, there is an urgent need for taxonomic identification of its components in order to, from there, know its biotechnological potential, as well as its biogeographic and ecological implications. The identification of the beach-cast seaweeds on the beach on the coast of Piauí is a pioneering study, in addition, this is the first record of a study of macroalgae on the beach of Itaqui. The objective of this study was to identify the beach-cast seaweeds in Itaqui beach, municipality of Luis Correia, Piauí, located in the northeastern of Brazil (2º 54'.6" S 41º 34' 28.1" W). Collections were carried out along the entire length of the wave breaking line, where the seaweeds were present during low tide, in July 2017. Taxonomic identification was performed under a stereomicroscope and microscope, based on morphological characters. 55 taxa were identified, with fourteen new occurrences for the Piauí coast: *Agardhiella ramosissima* (Harvey) Kylin, *Aglaothamnion felipponei* (Howe) Aponte, Ballantine & J.N.Norris, *Canistrocarpus crispatus* (J.V.Lamouroux) De Paula & De Clerck Clerck & al., *Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq, *Dichotomaria marginata* (J.Ellis & Solander) Lamarck, *Halimeda jolyana* Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen & S.M.B. Pereira, *Heterodasya mucronata* (Harvey) M.J.Wynne, *Heterosiphonia crispella* (C.Agardh) M.J.Wynne, *Hypnea cornuta* (Kützing) J.Agardh, *Laurencia translucida* Fujii & Cordeiro-

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Marino, *Meristotheca gelidium* (J.Agardh) E.J.Faye & M.Masuda, *Stypopodium zonale* (J.V.Lamouroux) Papenfuss, *Willeella ordinata* Børgesen, *Zonaria tournefortii* (J.V.Lamouroux) Montagne, in addition to *Gracilaria* spp., *Grateloupia* sp., *Hypnea* sp. that are potential new species.
Keywords: beach-cast seaweeds, marine biodiversity, stranded seaweeds.

RESUMO

A ficoflora no litoral do Piauí ainda está entre as menos estudadas no Brasil, principalmente no que diz respeito ao conhecimento do infralitoral. A flora do infralitoral no Brasil é conhecida principalmente pela análise de material arribado às praias. As algas marinhas arribadas são originárias de bancos de algais bentônicos, principalmente do infralitoral e ocorrem frequentemente em muitas praias do nordeste, sudeste e sul do Brasil, durante a maré baixa. Estudos apontam o grande potencial biotecnológico das algas com possibilidades de seu uso, na produção de ficocolóides, como alimentação humana, ração animal, fertilizantes, medicamentos, entre outros. No entanto, as macroalgas arribadas são tratadas como lixo, comumente incineradas ou coletadas para aterros sanitários. Portanto, há uma necessidade urgente de identificação taxonômica dos seus componentes para a partir daí, conhecer o seu potencial biotecnológico, assim como as suas implicações biogeográficas e ecológicas. A identificação de algas marinhas fundidas na praia do litoral do Piauí é um estudo pioneiro; além disso, este é o primeiro registro de um estudo de macroalgas na praia de Itaqui. O objetivo deste estudo foi identificar as algas encontradas na Praia de Itaqui, município de Luis Correia, Piauí, localizado no nordeste do Brasil (2º 54'.6" S 41º 34' 28.1" W). As coletas foram realizadas ao longo de todo o comprimento da linha de quebra de ondas, onde as algas estavam presentes durante a maré baixa, em julho de 2017. A identificação taxonômica foi realizada sob estereomicroscópio e microscópio, com base em caracteres morfológicos. Foram identificados 55 táxons, com quatorze novas ocorrências para a costa do Piauí: *Agardhiella ramosissima* (Harvey) Kylin, *Aglaothamnion felipponei* (Howe) Aponte, Ballantine e J.N.Norris, *Canistrocarpus crispatus* (J.V.Lamouroux) De Paula e De Clerck Clerck & ca., *Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq, *Dichotomaria marginata* (J. Ellis e Solander) Lamarck, *Halimeda jolyana* Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen e S.M.B. Pereira, *Heterodasya mucronata* (Harvey) M.J.Wynne, *Heterosiphonia crispella* (C.Agardh) M.J.Wynne, *Hypnea cornuta* (Kützing) J.Agardh, *Laurencia translucida* Fujii & Cordeiro-Marino, *Meristotheca gelidium* (J.Agardh) E.J.Faye & M.Masuda, *Stypopodium zonale* (J.V.Lamouroux) Papenfuss, *Willeella ordinata* Børgesen, *Zonaria tournefortii* (J.V.Lamouroux) Montagne, além de *Gracilaria* spp., *Grateloupia* sp., *Hypnea* sp. que são potenciais novas espécies.
Palavras-chave: algas arribadas, algas encalhadas na praia, biodiversidade marinha.

INTRODUCTION

The Brazilian coastline extends across 7367 km, being mostly within the tropical zone, with only the southern region in the subtropical zone (Simioni *et al*., 2019), where it houses great biodiversity of marine organisms. The number of algal species listed for Brazil is 4755, of those 1939 species are marine and about 750 species are benthic macroalgae (Flora do Brasil, 2020), occurring from the intertidal zone to 250 m depths in Brazilian waters (Henriques *et al*., 2014; Yoneshigue-Valentin *et al*., 2020). Despite the advances in the knowledge of the Brazilian algal flora, it is believed that these results are still underestimated. According to Horta *et al*., (2001), there are still gaps in the knowledge of macroalgae alongshore of Brazil, due to the little knowledge of some points on the coast of the northeastern as well as the knowledge of the phycoflora of the infralittoral that has been neglected.

For Pacheco (2011), the flora of the infralittoral in Brazil is known, mainly for the analysis of beach-cast seaweeds and from dredging and diving. Beach-cast seaweeds refer to benthic marine algae, which are pulled from their substrates and brought to the beaches. Considering that the subtidal algal flora is still poorly known in Brazil, the identification of the beach-cast seaweeds and biogeographic studies could perhaps shed light on this phenomenon. Menezes *et al*. (2015) suggested that the availability and diversity of beach-cast seaweeds are intrinsically related to the benthic phycoflora associated with each region.

The occurrence of the beach-cast seaweeds on the beach has been increasingly common. Seaweed strandings occur frequently on many coasts and are particularly important on sandy beaches (McLachlan & Brown, 2006). Patches of stranded macrophytes (wrack, beach-cast) are a distinctive feature of sandy beaches worldwide (McLachlan & Brown, 2006; MacMillan & Quijón, 2012; López *et al*., 2017). As an example, Zemke-White *et al*. (2005) estimated that up to 25% of annual kelp production may end up as beach-cast seaweeds. Kelp forests are very productive communities and one of the dominant species is *Macrocystis pyrifera* (Linnaeus) C. Agardh, commonly known as giant kelp that it occurs in both the North Hemisphere (western coast of North America) and the South Hemisphere (Australia, New Zealand, South Africa, sub-Antarctic islands, and the western and eastern coasts of South America) (Batista *et al*., 2018). In tropical areas, there is an increasing trend of massive strandings (mainly pelagic seaweeds, such as *Sargassum*), which has been related to climate change (Gower *et al*., 2006; Gower & King, 2011). Pelagic seaweeds have been identified in the North and Central Atlantic, Caribbean Sea, and West Africa, and together create the Great Atlantic *Sargassum* Belt (GASB) (Wang *et al*., 2019). These so-called monospecific algal blooms are most frequently related to two pelagic *Sargassum* species: *S. fluitans* (Børgesen) Børgesen and *S. natans* (Linnaeus) Gaillon (Oyesiku & Egunyomi, 2014; Cuevas *et al*., 2018; Putman *et al*., 2018; Wang *et al*., 2019).

Massive floating *Sargassum* blooms, from the GASB, were first reported off the shore of northern Brazil in July 2011 by Széchy *et al*. (2012) and again in 2014 and 2015 (Sissini *et al*., 2017). However, the most common unattached seaweeds observed in the tropical regions along the Brazilian coast are multispecific and typically composed of various species of red, brown and green algae (Câmara-Neto, 1971; Câmara-Neto *et al*., 1981; Pedrini, 1984; Calado *et al*., 2003; Santos *et al*., 2013; Vila Nova *et al*., 2014). Various physical and biological factors can influence the detachment of macroalgae from the rocky bottoms (Dayton *et al*., 1992; Pennings *et al*., 2000). Currents and storm-winds that acting together are the main causes of that detachment of buoyant seaweeds from rocky habitats which occurs mainly during storms when strong waves cause the rock substratum to break or part of the specimens (Santelices *et al*., 1980; Zemke-White *et al*., 2005; Duarte *et al*., 2008; Garden *et al*., 2011).

Due to the frequency of records of occurrence of beach-cast seaweeds along the Brazilian coast, some studies have been carried out in the northeastern (Praciano, 1977; Câmara-Neto *et al*., 1981; Santos *et al*., 2013) and southeastern regions (Pedrini, 1984). However, detailed taxonomic studies are still insufficient and ecological studies are extremely scarce. Schreiber *et al*., (2020) say that the relationship between benthic populations and stranded seaweeds has received little attention, what after detachment, a fraction of floating specimens return to the shore, resulting in strandings that fluctuate in space and time. Factors such possibility of dispersion, influenced by currents, can modify the distribution pattern of marine species. According to Batista *et al*. (2018) currents acting together with storm-winds are efficient dispersal mechanisms for floating strategists and associated communities. In the South Atlantic more frequent and intense storms, related to global warming, have been observed in recent decades, which compromise oceanic circulation and migration processes.

On the other hand, the presence of the beach-cast seaweeds in the beaches brings negative consequences for the municipalities' economy. The presence of these algae is negative for tourism and this biomass, in Brazil, is often underutilized or destined for landfills (Santos *et al*., 2013). The beach-cast seaweed biomass interferes with recreational uses of the beaches and therefore must be periodically collected and disposed of (Piriz *et al*., 2003; Cuevas *et al*., 2018), because the accumulation of these algae can affect human use and beach pleasure, when they decompose, producing hydrogen sulfide gas (Hansen, 1984) and beach fly pests (Blanche, 1992). So, the harvesting of beach-cast seaweeds is carried out by the city halls in order to keep the beaches in good conditions for recreational activities (Cuevas *et al*., 2018). Therefore, this biomass is being collected without records of its composition, accordingly without knowledge and use of its potential and even more without considering the ecological importance and the environmental impacts promoted by this action. According to Gavio *et al*., (2015), the fact that these events have become recurrent is alerting scientists as well as the affected communities, where tourism, fishing, and other economic activities have been disrupted.

To most people, beach-cast seaweeds are piles of rotting plant material washed up along the high tide line of many beaches, for other few people, these accumulations are livelihoods and represent the raw product of a valuable resource. According to Kirkman & Kendrick (1997), the managed harvesting of specific areas, where wracks are seen as problems, can produce a variety of economic products: cattle feed, garden fertilizers, soil improvers, mariculture feeds, and such value-added products as alginate and agars, and in adition to reduce inorganic nutrients and organic matter from eutrophicated coastal waters (Piriz *et al*., 2003), production of biogas (Eyras *et al*., 1998) and in the cleaning of coastal beaches for recreation and tourism. It is urgent to understand the causes of these events, which may disrupt shallow ecosystems like seagrass and macroalgal beds, and affect local communities disrupting their economic activities. In order to establish sound management and utilization strategies, qualitative analyses and quantification of the wrack are necessary. However, few studies have been focused on this area (Piriz *et al*., 2003).

For the first time, a study is carried out on the beach-cast seaweeds on the beach of the coast of Piauí, moreover, this is the first record of a study of macroalgae on the beach of Itaqui in which species were identified and our results were compared with other existing ones, both for the benthic flora of the coast of Piauí and with studies of the Brazilian infralittoral coast. Our hypothesis was that the study of the beach-cast seaweeds should bring an increase in the knowledge of the benthic marine flora on the infralittoral region to the coast of Piauí. This analysis is considered an important subsidy for expanding knowledge about the algal flora of this region and for providing information about this resource made available by nature with the possibility of being used by the local community.

MATERIAL AND METHODS

Study area

Itaqui Beach is located in the municipality of Luis Correia, Piauí, the northeastern region of Brazil (2º54'.6 "S, 41º34'28.1" W), according to the Köppen classification, the coastal climate in Piauí is rainy, hot and humid (Aw ') tropical type, with high rainfall, in summer and autumn due to the influence of the Equatorial Atlantic mass, between the months of January and June and with average temperatures of 27º C. According to Horta *et al*. (2001), Piauí is inserted in the tropical zone that has specific phychogeographic characteristics, for presenting a relatively rich flora, established predominantly on sandstone reefs encrusted with limestone algae and corals, having as its northern limit the west of Ceará and as the southern limit, the south of the state of Bahia. The region is characterized by oligotrophic waters and an abundance of hard substrates, conducive to the growth of benthic algae (Oliveira Filho, 1977; Castro-Filho & Miranda, 1998) (fig. 1).

Sample processing

Collections were carried out along the entire length of the wave breaking line, where the seaweeds were present during low tide, in July 2017. The collected material was placed in Ziploc plastic bags immediately frozen at -20ºC and transported to the laboratory of the Institute of Botany, in São Paulo, SP, where, then, the species were identified (Barbosa *et al*., 2008; Nunes, 2010; Santos *et al*., 2013). Identification was based on morphological characters and the systematization of the taxa is in accordance with Wynne (2017) and Guiry & Guiry (2020). The confirmation of species registration for the Piauí coast was carried out through Flora do Brasil (2020). As well as through studies already carried out for this region. Samples were deposited in the "Maria Eneyda P. Kauffman Fidalgo" herbarium of the Institute of Botany (SP), São Paulo, Brazil, and in the herbarium of the Institute Federal of Piauí, Piauí, Brazil.

RESULTS

In this study, 55 taxa were identified, among them 33 Rhodophyta, 13 Ochrophyta, and 9 Chlorophyta. 14 new occurrences were recorded for the coast of Piauí (figures 2-15), in addition to four potential new species: *Gracilaria* sp. 1, *Gracilaria* sp. 2, *Grateloupia* sp. and *Hypnea* sp. (Table 1).

Table 1. Updating the flora of benthic marine algae off the coast of the state of Piaui, Brazil.

Taxa	Copertino & Mai 2010.	Batista 2011	Alves & Carvalho 2012	Voltolini *et al*. 2012	Santiago 2016	Assis & Alves 2017	Present Study	Other studies
Ochrophyta Phaeophyceae Dictyotales								
Canistrocarpus cervicornis					x		x	
Canistrocarpus crispatus							x	
Dictyopteris delicatula		x		x	x		x	
Dictyota bartayresiana					x			
Dictyota menstrualis		x		x	x			

Dictyota mertensii	x					x	x	
Dictyota pulchella					x			
Lobophora variegata	x	x			x	x	x	
Padina gymnospora	x	x		x	x	x	x	
Spatoglossum schroed-eri					x		x	
Stypopodium zonale							x	
Zonaria tournefortii							x	
Ectocarpales								
Colpomenia sinuosa					x		x	
Fucales								
Sargassum cymosum						x		
Sargassum filipendula		x					x	
Sargassumstenophyllum		x						
Sargassum vulgare	x	x			x	x	x	
Rhodophyta Florideophyceae Bangiales								
Pyropia vietnamensis					x			a
Ceramiales								
Acanthophora spicifera	x			x	x	x		
Aglaothamnion felippo-nei							x	
Alsidium seaforthii	x				x*	x*	x	
Alsidium triquetrum					x			
Amansia multifida					x		x	
Bostrychia tenella						x		
Ceramium brasiliensis						x		
Ceramium sp.							x	
Haloplegma duperreyi				x	x	x	x	
Heterodasya mucronata							x	
Heterosiphonia crispella							x	
Laurencia dendroidea				x		x		
Laurencia translucida							x	
Osmundaria obtusiloba						x	x	
Osmundaria sp.							x	
Palisada flagellifera						x	x	
Palisada perforata				x		x	x	
Spyridia clavata					x			
Corallinales								
Corallina officinalis						x	x	

Corallina panizzoi		x					
Jania capillacea		x				x	
Jania pedunculata var. adhaerens	x				x*		
Jania crassa							
Jania subulata			x		x		
Tricleocarpa cylindrica		x			x		
Tricleocarpa fragilis	x						
Erythropeltidales							
Madagascaria atlantica							d
Gelidiales							
Gelidiella acerosa		x	x		x		
Gelidium calidum							b
Gelidium crinale				x			
Gelidium microdonticum					x*		
Gelidium pusillum		x			x		
Pterocladiella bartlettii							c
Gigartinales							
Agardhiella ramosíssima						x	
Calliblepharis occiden-talis				x		x	
Hypnea pseudomuscifor-mis	x	x	x*	x	x*	x	
Hypnea cornuta						x	
Hypnea spinella		x	x		x		
Hypnea sp.						x	
Meristotheca gelidium						x	
Ochtodes secundiramea				x			
Solieria filiformis		x		x		x	
Gracilariales							
Crassiphycus birdiae			x*	x*	x*		
Crassiphycus caudatus						x	
Crassiphycus corneus				x*	x*		
Gracilaria cearensis				x			
Gracilaria cervicornis	x			x	x		
Gracilaria cuneata					x		
Gracilaria curtissiae				x		x	
Gracilaria domingensis			x	x	x	x	
Gracilaria ferox				x			
Gracilaria flabelliformis				x			

Gracilaria hayi				x			
Gracilaria intermedia				x			
Gracilaria sp. 1						x	
Gracilaria sp. 2						x	
Gracilariopsis silvana				x			
Halymeniales							
Cryptonemia crenulata	x			x	x	x	
Cryptonemia seminervis				x	x	x	
Grateloupia sp.						x	
Nemaliales							
Dichotomaria marginata						x	
Dichotomaria obtusata					x		
Tricleocarpa cylindrica					x		
Rhodaclyales							
Rhodachlya westii							e
Rhodymeniales							
Botryocladia franciscana				x			
Botryocladia occidentalis				x	x	x	
Sebdeniales							
Sebdenia flabellata				x			
Chlorophyta, Ulvophy-ceae **Bryopsidales**							
Avrainvillea longicaulis		x					
Bryopsis pennata		x				x	
Caulerpa ashmeadii		x					
Caulerpa cupressoides var. *elegans*							
Caulerpa cupressoides var. *lycopodium*	x	x		x			
Caulerpa cupressoides var. *serrata*		x		x			
Caulerpa denticulata				x			
Caulerpa floridana				x			
Caulerpa mexicana	x	x	x	x	x		
Caulerpa prolifera	x	x		x	x	x	
Caulerpa racemosa	x			x	x	x	
Caulerpa racemosa var. *occidenatalis*		x			x		
Caulerpa racemosa var. *uvifera*		x			x		
Caulerpa scalpelliformis		x			x		
Caulerpa sertularioides	x	x		x	x		

Caulerpa sertularioides f. *longiseta*					x		
Codium intertextum			x				
Codium isthmocladum	x				x	x	x
Codium taylorii			x		x	x	
Halimeda jolyana							x
Cladophorales							
Cladophora dalmatica		x					
Cladophora prolifera						x	x
Cladophora vagabunda		x	x*			x	x
Cladophoropsis membranacea				x*			
Chamaedoris peniculum					x		
Pseudorhizoclonium africanum			x*				
Rhizoclonium riparium		x					
Valonia aegagropila				x	x	x	
Willeella ordinata							x
Dasycladales							
Acetabularia calyculus	x	x	x	x	x		
Acetabularia crenulata		x		x			
Ulvales							
Gayralia oxysperma		x		x*			
Ulva compressa			x			x	
Ulva flexuosa		x					
Ulva intestinales			x				
Ulva lactuca	x	x	x*	x*	x	x	x
Ulva rigida					x		

*Nomenclatural updates made based on AlgaeBase (https://www.algaebase.org/).
a = Milstein *et al*. (2015); b = Jamas *et al*. (2017); c = Iha *et al*. (2017); d = Soares *et al*. (2019); e = Soares *et al*. (2020).

DESCRIPTION OF NEW OCCURRENCES:

Phylum Ochrophyta

Canistrocarpus crispatus (J.V.Lamouroux) De Paula & De Clerck. Fig. 2 (A-F).

Basionym: *Dictyota crispata* J.V.Lamouroux

Type locality: Antilles, Caribbean Sea

Description: Greenish-brown thallus, up to 30 cm high, attached to the substrate by rhizoids emerging from the base and proximal portions of the base. Blade with a smooth margin, in the form of a narrow row, 4-6 mm in the middle portion of the tape. Dichotomous branching and alternating closed-angle, with sharp, beveled, or rounded apexes. The medullary region consisting of a layer of small, quadratic, and pigmented cells. Medullary region by a layer of colorless, large, quadratic to rectangular cells. Sporangia isolated or grouped, surrounded by a ring of sterile cells. Antheridial sori often found in every thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Stypopodium zonale* (J.V.Lamouroux) Papenfuss**. Fig. 3 (A-C).

Basionym: *Fucus zonalis* J.V.Lamouroux

Type locality: Dominican Republic

Description: Yellowish-brown to dark brown thallus, up to 45 cm high, fixed to the substrate by a discoid holdfast, composed of rhizoidal filaments. The thallus of malleable consistency, often split longitudinally into segments of wedged apexes, with cross hairlines and growth by unrolled apical cell margins. In cross-section, a thallus formed by a layer of pigmented cortical cells and four layers of colorless medullary cells, larger than the cortical ones, in the median region. Sporangia distributed irregularly throughout the thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Zonaria tournefortii* (J.V.Lamouroux) Montagn .** Fig. 4 (A-E).

Basionym: *Fucus tournefortii* J.V.Lamouroux

Type locality: Corsica; southern France; Italy

Description: The thallus of shrubby habit, dense, greenish-brown in color, up to 20 cm high, fixed to the substrate by an holdfast composed of strongly intertwined rhizoidal filaments. Flabeliform thallus of rigid consistency, with central rib, restricted to more developed portions, smooth margins, and radial streaks. Laminar portion with dichotomous to irregular branching. Appendages wedged and not rolled, formed by rows of cells longitudinally split and expanded. In a superficial view, cortical cells are quadratic to rectangular, perfectly aligned longitudinally two by two. In cross-section, thallus formed by a layer of pigmented cortical cells and four layers of colorless cells, larger than the cortical ones.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Phylum Rhodophyta

***Agardhiella ramosissima* (Harvey) Kylin.** Fig. 5 (A-B).

Basionym: *Chrysymenia ramosissima* Harvey

Type locality: Key West, Florida

Description: Intense red thallus, erect, isolated, slippery, leathery texture, up to 46 cm high, fixed to the substrate by a discoid base. Flat ribbon-shaped axes, up to 1.3 cm in diameter, abundantly branched, in a dystic manner. Branches with a constricting base, usually dissected by numerous short, spinous branches. In cross-section, the internal cortical region with 3 to 4 layers of small, pigmented cells, rounded to oval and external cortical region with 3 to 4 layers of large, colorless, rounded to quadratic cells. Medullary region composed of branched filaments, interlaced, loosely arranged. Zoned tetrasporangia, scattered over the last order branches.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

***Aglaothamnion felipponei* (Howe) Aponte, Ballantine & J.N.Norris.** Fig. 6 (A-B).

Basionym: *Callithamnion felipponei* Howe

Type locality: Cabo de Santa Maria, Rocha, Uruguay.

Description: Thallus filamentous, pinkish-reddish, forming delicate tufts of shrublike aspect, up to 4 mm high, fixed to the substrate by typed multicellular rhizoids. Uninucleate cells. Evident main axis, 50-75 µm in diameter, with alternating, dense branching in several planes. Narrower branches towards the apex and branches of last order are typically curved. Basal cells are quadratic, while apical cells are thin and elongated, up to 12.5 × 75 µm in diameter.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Crassiphycus caudatus* (J.Agardh) Gurgel, J.N.Norris & Fredericq**. Fig. 7 (A-C).

Basionym: *Gracilaria caudata J.Agardh*

Type locality: Gulf of Mexico

Description: Red to reddish-brown Thallus, cylindrical, forming curved tufts, up to 10 cm high, attached to the substrate by a small discoid holdfast. Shafts up to 1.5 mm in diameter, with branching generally unilateral to irregular. Branches decreasing in diameter towards the apex. Some branches with constrained bases. In cross-section, 1 to 2 layers of small cortical cells, the outermost being oval and with up to 11 layers of rounded medullary cells, with numerous floridean starch grains. Gradual transition between the cortical and medullary regions. When present, cruciate tetrasporangia, spread on the surface of the thallus.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Dichotomaria marginata* (J.Ellis & Solander) Lamarck .** Fig. 8 (A-D).

Basionym: *Corallina marginata* J.Ellis & Solander

Type locality: Bahamas

Description: Erect, reddish-brown, flattened thallus, up to 15 cm high, fixed to the substrate through a holdfast. Dichotomous to pseudodichotomic branching, with mild calcification. Branches with rounded apices. In cross-section, the gametophytic thallus has a filamentous medulla and cortex with three layers of cells and apiculate cells that are formed mainly at the margins of the thalli, from external cortical cells. There are no apiculate cells in the tetrasporophytic thalli**.**

Distribution on Brazilian coast: Northeastern, Southeastern, and South coast.

***Heterodasya mucronata* (Harvey) M.J.Wynne.** Fig. 9 (A-D).

Basionym: *Dasya mucronata* Harvey

Type locality: Key West, South Florida

Description: Thallus shrubby, feathery, erect, red to pinkish red, up to 20 cm high, with one or more axes fixed to the substrate by a small discoid base. Cylindrical and cross-sectional branches have five pericentral cells. The branching is radial to irregular. The upper branches are covered by branches (trichoblasts), giving the thallus a shrublike appearance. The molds are mucronated and uniseriate and show apical and monopodial growth, arranged in a spiral pattern alternate or subdichotomous. When present, sporangia are tetrahedrally divided and cystocarps are ostiolated.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

***Heterosiphonia crispella* (C.Agardh) M.J.Wynne .** Fig. 10 (A-E).

Basionym: *Callithamnion crispellum* C.Agardh

Type locality: Cádiz, Spain

Description: Rosy-reddish, corticated thallus, up to 1 cm high, forming delicate rugs on the host. Main cylindrical shaft, branched every 2 segments, in an alternating and abundant manner. Monosiphonic branches with subdichotomous branching, at an open angle, formed by approximately quadratic cells. Acuminated apices. Tetrahedral *tetrasporangia*, up to 3 per segment, organized in *stichidium*, usually originating from the median region of the lateral branches. Gametophytes were not observed.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

***Hypnea cornuta* (Kützing) J.Agardh.** Fig. 11 (A-F).

Basionym: *Chondroclonium cornutum* Kützing

Type locality: "ad oras Guineae"

Description: Erect thallus, cartilaginous texture, brownish-yellow color, up to 15 cm high, fixed to the substrate by primary cutting disc or rhizoidal branches. Little or unbranched thallus. Main cylindrical and evident branch, 937–1350 µm in diameter. Apice erect and acute, 371–435 µm in diameter. Alternatively arranged modules with a logistical tendency. Axial cells much smaller than as peiraxial, as which are rounded to ovals, in a number of 5 or 6, 2 or 3 layers of medial hyaline cells, 1 or 2 layers of cortical cells. Abundant lenticular thickening in the walls of the periaxial and or medullary cells. Cut very thick around the entire thallus. Tetrasporangia, surrounding a basal and median part of the shafts. Examples of gametophytes not found.

Distribution on Brazilian coast: Northeastern (Piauí, Maranhão, Bahia), Southeastern (Rio de Janeiro, São Paulo) and South (Paraná) coast.

***Laurencia translucida* Fujii & Cordeiro-Marino.** Fig. 12 (A-D).

Type locality: Praia do Padre, Aracruz, Espírito Santo, Brazil

Description: Vinous-red to greenish-red thallus, erect, forming isolated, delicate tufts, up to 12 cm high, attached to the substrate by one or more aggregated discoid holdfasts. Dense branching, alternating the spiral, producing rulers in up to 3 orders. In a superficial view, translucent external cortical cells, without secondary connections between them and pigmented internal cortical cells, with secondary connections. In a longitudinal section, cortical cells not projected beyond the surface of the thallus. In cross section, 2 layers of cortical cells, the outermost composed of translucent cells, with a slightly triangular outline and the innermost composed of the square to irregular cells. Medullary region composed of 4 to 5 layers of cells. Each vegetative axial segment produces 2 pericentral cells.

Distribution on Brazilian coast: Northeastern, Southeastern and South coast**.**

Nordeste (Bahia, Ceará, Paraíba, Pernambuco)

Sudeste (Espírito Santo)

Sudeste (Espírito Santo)

Nordeste (Bahia, Ceará, Paraíba, Pernambuco)

Sudeste (Espírito Santo)

Meristotheca gelidium **(J.Agardh) E.J.Faye & M.Masuda**. Fig. 13 (A-D).

Basionym: *Sphaerococcus gelidium* J.Agardh

Type locality: Brazil

Description: Vinous red to greenish-yellow thallus, firm texture, subcartilaginous, with flattened branches, up to 60 cm high, attached to the substrate by a small discoid holdfast. Branching alternates the sub-opposite, most of the time couplet, with branches in up to 3-6 orders. Branches up to 2 cm wide, from sub-cylindrical to flat, tapered towards the apex. Branches of last order short and spinous or elongated and flexible. Multiaxial apex, pit-connection between adjacent axial filaments. Interconnection of missing cells and filaments. In cross-section, cortex with 3-4 layers of pigmented cells and medulla with filaments and rhizoid. Tetrasporangia zoned over the entire surface of the thallus, except the base and cystocarps in the last order branches with spinning projections.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Phylum Chlorophyta

Halimeda jolyana **Ximenes, Bandeira-Pedrosa, Cassano, Oliveira-Carvalho, Verbruggen & S.M.B.Pereira** Fig. 14 (A-C).

Type locality: Castelhanos beach, Anchieta, Espírito Santo, Brazil

Description: Green to dark green thallus up to 2.5 cm high, fixed to the substrate by a large discoid holdfast. Thallus with mild calcification, composed of very thick segments, 1.7-3.0 mm, coined to discoid. In a superficial view, the primary utricles appear in a polygonal pattern (mainly hexagonal), firmly pressed against each other. Branching often forked.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

Willeella ordinata **Børgesen.** Fig. 15 (A-D).

Type locality: Port Okha, Gujarat, India

Description: Dark green, filamentous thallus approximately 2.5-7.5 cm long. Opposite branching in one plane, opposite at the apex of the thallus and conical apical cells, giving a pinched appearance to the stem. Main axis cells are longer than wide. Chloroplasts in polygonal cells, interconnected, forming a parietal network with a central pyrene.

Distribution on Brazilian coast: Northeastern and Southeastern coast.

DISCUSSION

After compiling and analyzing the results of previous studies of phycoflora from the coast of Piauí (Copertino & Mai, 2010; Batista, 2011; Alves & Carvalho, 2012; Voltolini *et al*., 2012; Santiago, 2016; Assis & Alves, 2017) the present study revealed an algal flora extremely rich, concentrated in a reduced area if we take into account that it was carried out on a single beach, where 14 new occurrences were recorded, increasing to 122 the number of taxa in the Piauí coast. Red algae group presented higher richness (60%) followed by brown (23.6%) and green algae (16.4%). This result is in agreement with other studies carried out in subtidal region (Horta, 2000; Yoneshigue-Valentin *et al*., 2006; Cocentino, 2009).

Based on the richness data and the frequent association between beach-cast seaweeds and rhodoliths, common substrates present in constantly submerged regions, lends support in favor of the subtidal origin of these algae. The number of species recorded in the present study is similar to that reported for other locations in the North Atlantic (Barbera *et al*., 2003) and in the South Atlantic (Riul *et al*., 2009) in studies of phycoflora associated with rhodoliths. The rhodolith beds are one of the most important benthic communities in the Brazilian continental shelf, providing a three-dimensional structure that transforms homogeneous backgrounds and unconsolidated sediments into heterogeneous hard substrates, consequently expanding the available niches and promoting increased species diversity, including commercially important and endemic species (Riul *et al*., 2009; Amado-Filho *et al*., 2010; Nunes & Andrade, 2017).

The predominance of the orders Ceramiales, Dictyotales and Bryopsidales among the red, brown and green algae, respectively also in relation to the others in other studies of benthic phycoflora (Pedrini, 1984; Altamirano & Nunes, 1997; Nunes & Paula, 2002; Barata, 2004; Marins *et al*., 2008; Barbosa, 2010; Santos *et al*., 2013) in the southeastern and northeastern of Brazil.

The results found in this study confirm our hypothesis regarding the contribution of increased knowledge of the flora of the benthic algae, since 14 new occurrences were identified on the coast of Piauí, which was surprising since the study was carried on a single beach. As for the origin, these species had already been identified in other studies of the infralittoral, both in the northeastern region (Riul *et al*., 2009) and in the southeastern (Pacheco, 2011) of Brazil, confirming the origin of a beach-cast seaweeds, in fact, is related to the subtidal region.

Bell & Hall (1997) suggested that less active environments favor the growth of benthic macroalgae than those with higher current speeds and/or extensive exposure to waves. While Berglund *et al*. (2003) suggested that the occurrence of beach-cast seaweeds was affected by exposure to the waves and that the greater the exposure the greater the accumulation. Several studies indicate that the biomass of the beach-cast seaweeds is influenced by currents, storms, substrates, nutrients, seasonality, light, competition, near floristic stock (Orr *et al*., 2005; Biber, 2007; Barbosa *et al*., 2008), although our ability to predict temporal patterns of stranded macroalgae biomass is still limited (López *et al*., 2018).

The presence of beach-cast seaweeds to the coastal zone is an important resource to be considered, due to the secondary metabolites they have and their application in the food, pharmaceutical or agricultural industries (Conde, 2019). The use of beach-cast seaweeds avoids the exploitation of natural algae populations (pruning in situ), which causes the disappearance and alarming decrease of this resource (Areces *et al*., 1993; Moreira *et al*., 2006). Studies indicate that beach-cast seaweeds of the Brazilian coast are promising as fertilizers (Barbosa, 2010; Sacramento *et al*., 2013; Vila Nova *et al*., 2014). However, before collection for commercial purposes, it must be determined what environmental impacts might be caused by this harvest. Kirkham & Kendrick (1997) pointed out that it is necessary to understand the link between the living resource offshore and the beach-cast seaweed. This information should be obtained at least for the main species and areas subject to commercial harvest. There are several key research gaps that need to be addressed in order to make decisions on the management of this resource or to determine the effects of removal. These gaps fall into two classes relating to biomass and availability of the resource followed by the effects of its removal on coastal ecosystems (Zemke-White *et al*., 2005).

This was the first beach-cast seaweeds study carried out on the coast of Piauí and it provided an opportunity to expand the biodiversity of the algae known for this coast. Such new findings indicate that biodiversity and marine flora is still underestimated. Additional phycological studies in this beach, particularly in deepwater habitats and other less collected environments, are likely to further increase the biodiversity of known algae in the region. The diversity of seaweed found in this study calls attention to this potential for renewable energy that has been disregarded or underutilized throughout the Brazilian coast. In conclusion, despite the apparent biotechnological potential of beach-cast seaweeds, this area of research and development is still relegated or underused. Further studies monitoring the occurrence, chemical composition, and taxonomic identification of beach-cast seaweeds are necessary for understanding how to utilize this biomass, a potential source of alternative biofunctional products when natural resources are being depleted.

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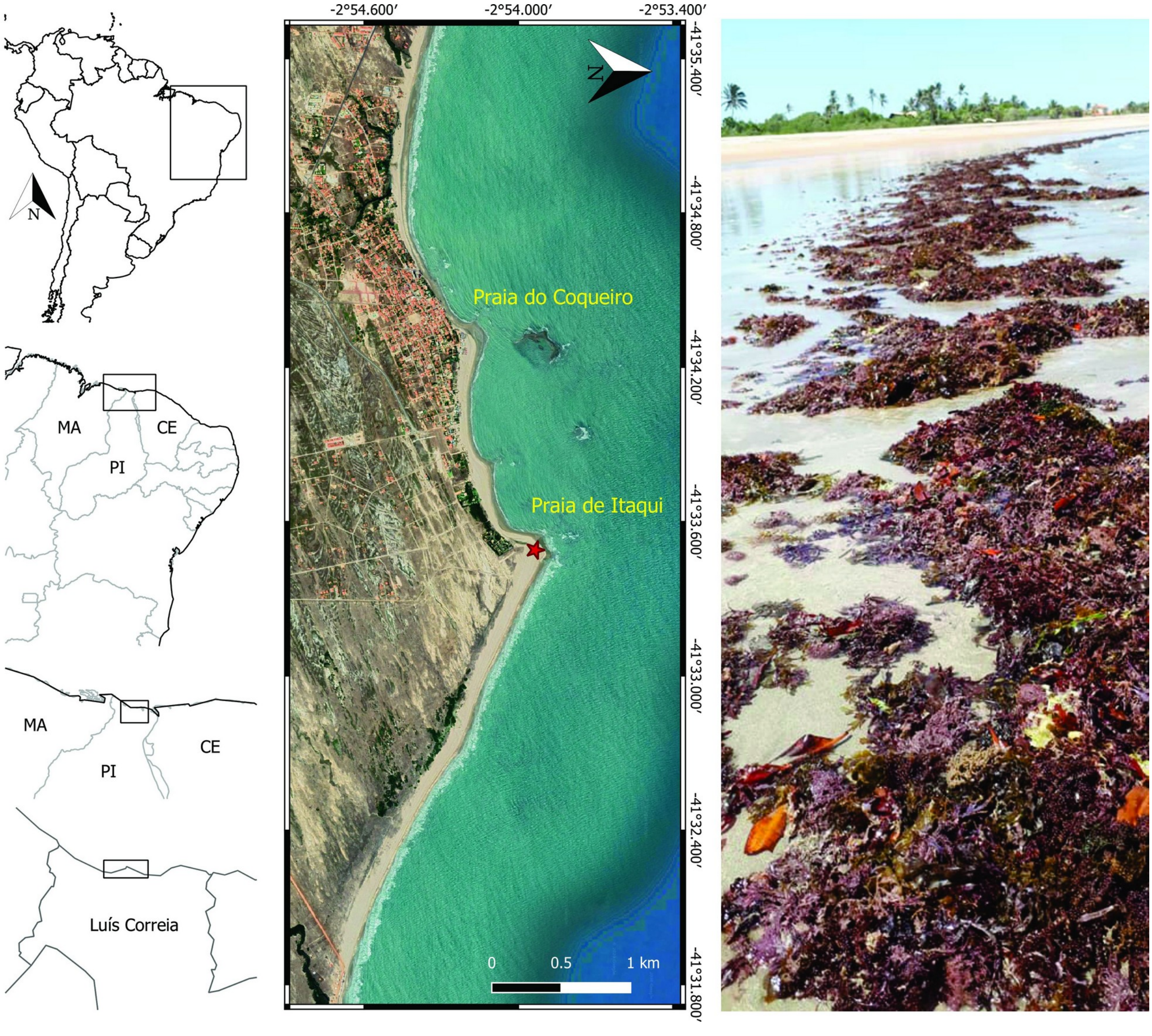

Figure 1. Map of Brazil with collection site at Praia de Itaqui, Luís Correia, Piaui, northeastern Brazil.

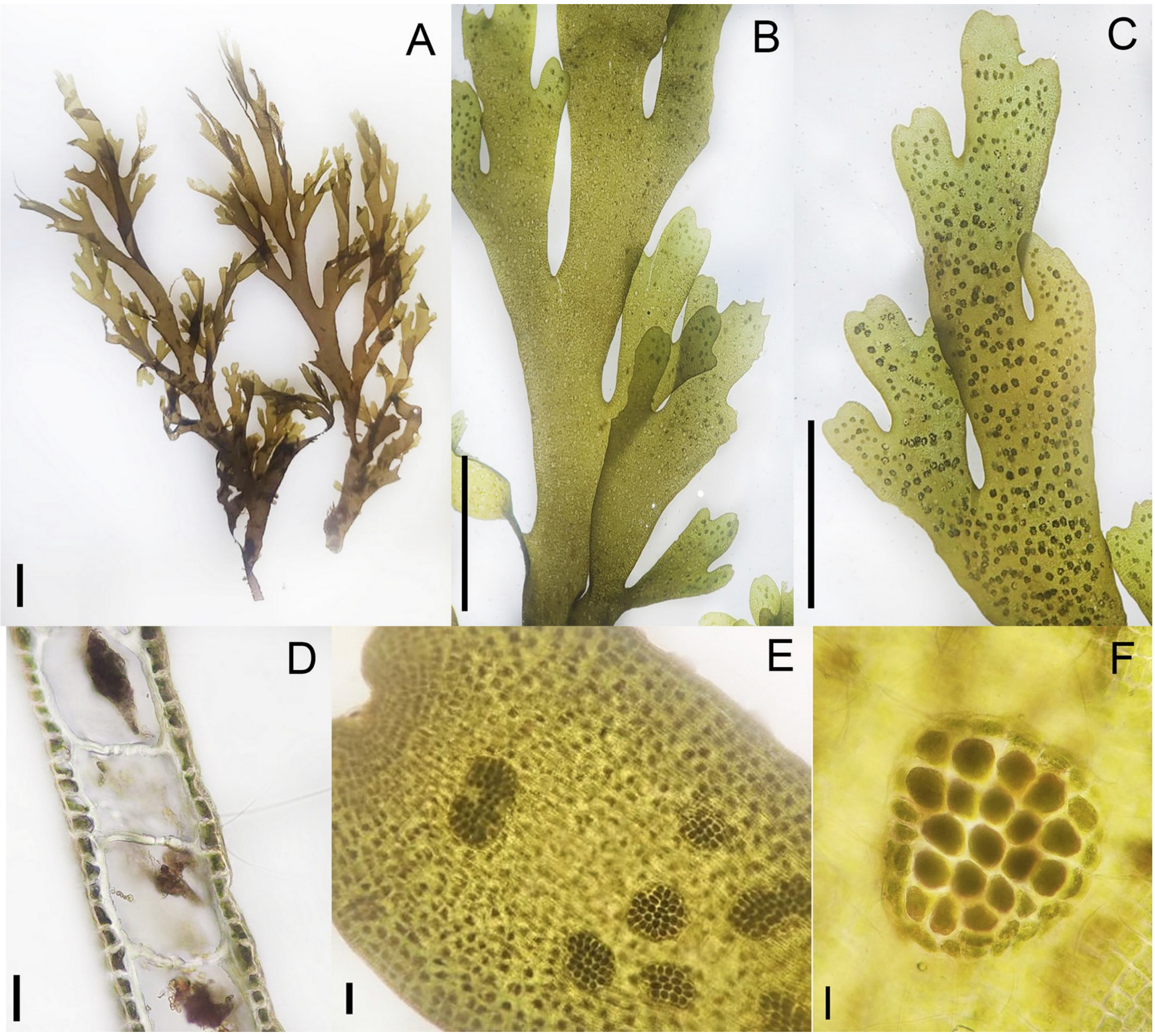

Figure 2. *Canistrocarpus crispatus.* A. General aspect of the thallus. B-C. Superficial view of the thallus. Branch showing alternating dichotomous branching. D. Cross-section of the branch. E. Superficial view of the branch with sporangia (dark spots). F. Superficial view of sporangia surrounded by a ring of vegetative cells. Scales: A=1 cm; B-C=0,5 cm; D, F=25 µm; E=100 µm.

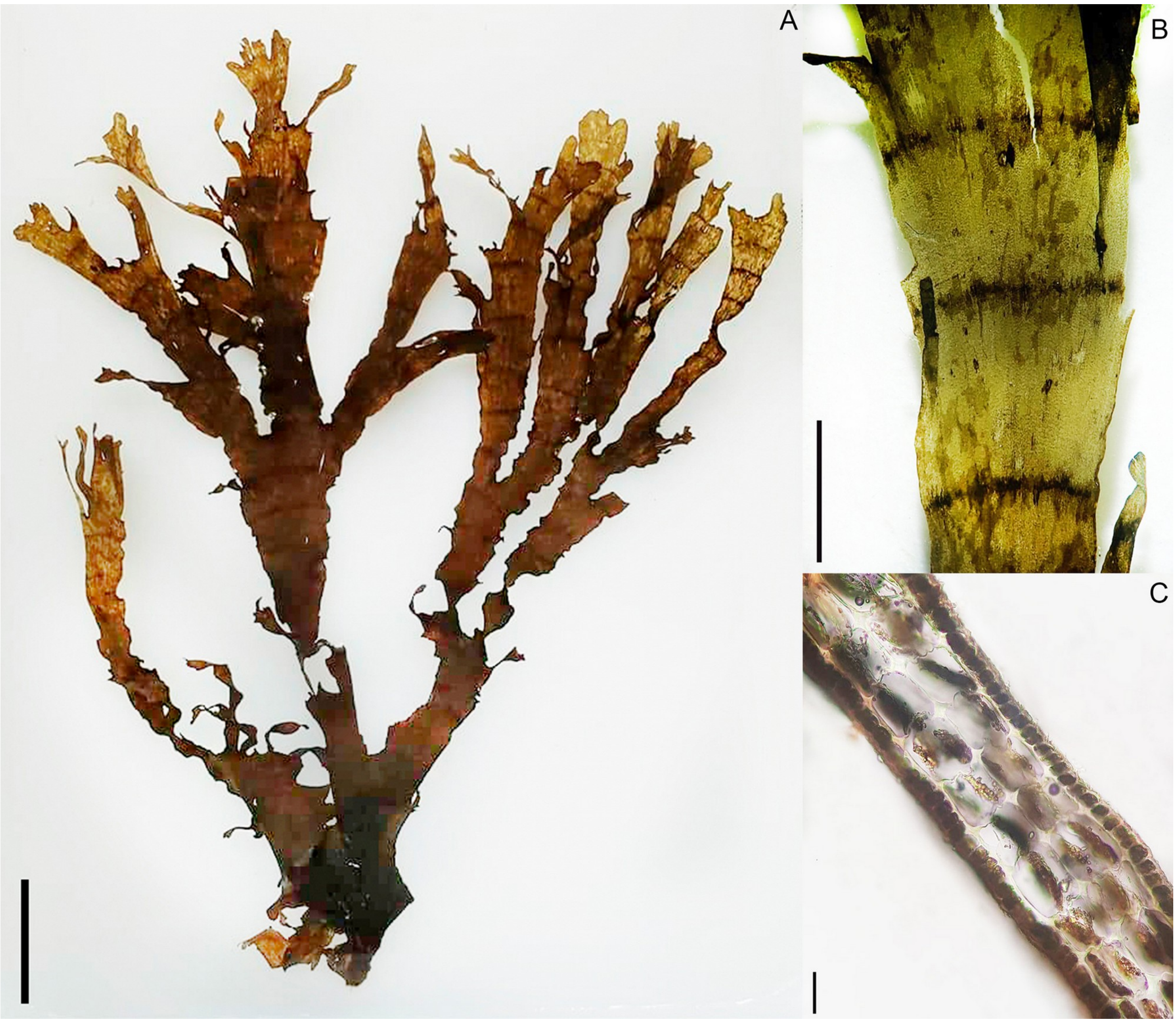

Figure 3. *Stypopodium zonale.* A. General aspect of the thallus. B. Superficial view of the branch. Branch showing cross hair lines C. Cross-section of the thallus apical region. Scales: A-B=1 cm; C=2 µm.

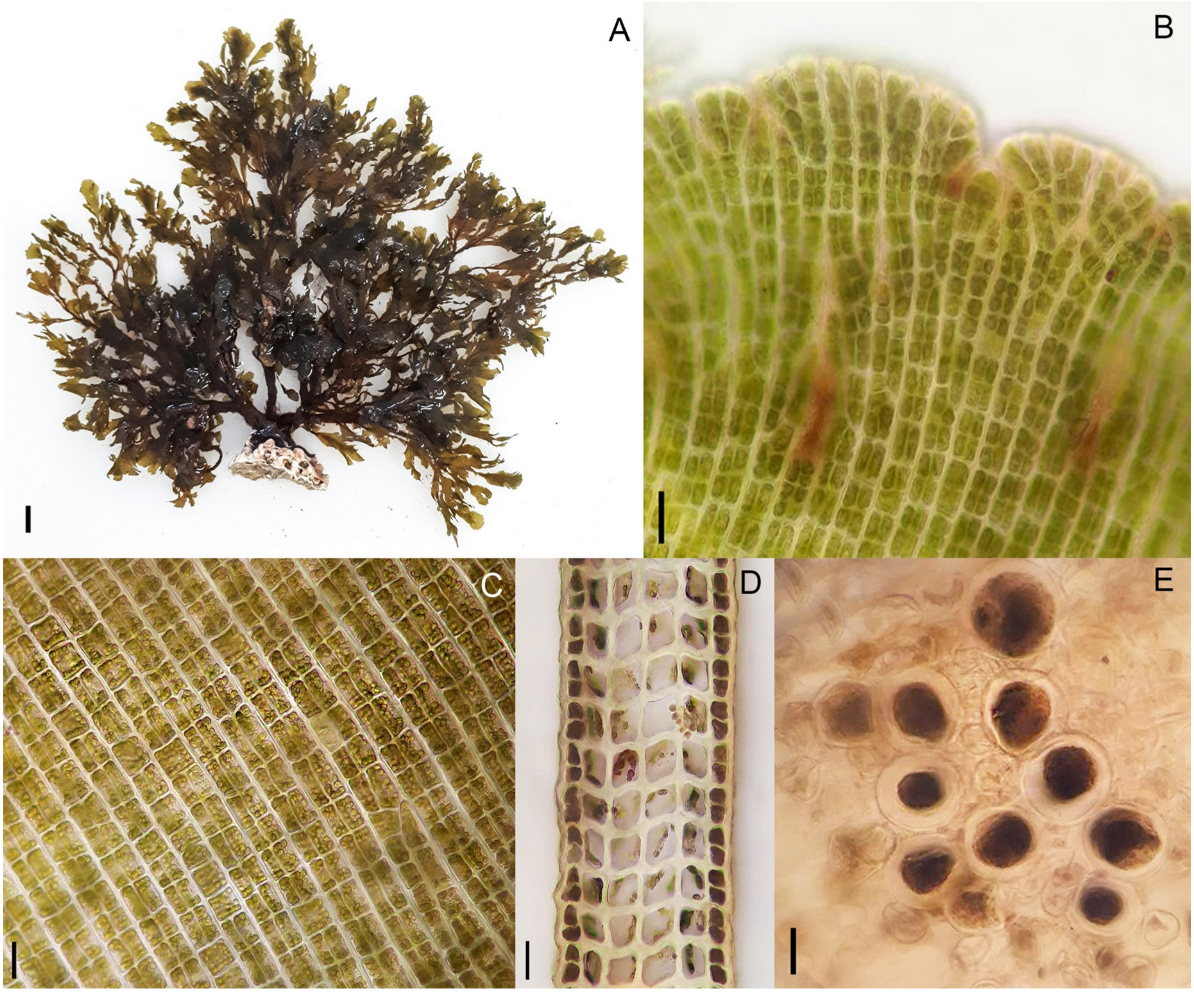

Figure 4. *Zonaria tournefortii.* A. General aspect of the thallus. B-C. Superficial view of the apical and median region of the thallus. Cortical cells perfectly aligned two by two. D. Cross-section of the thallus. E. Superficial view of the thallus. Branch showing oogonium. Scales: A=1 cm; B-C =100 µm; D-E=25 µm.

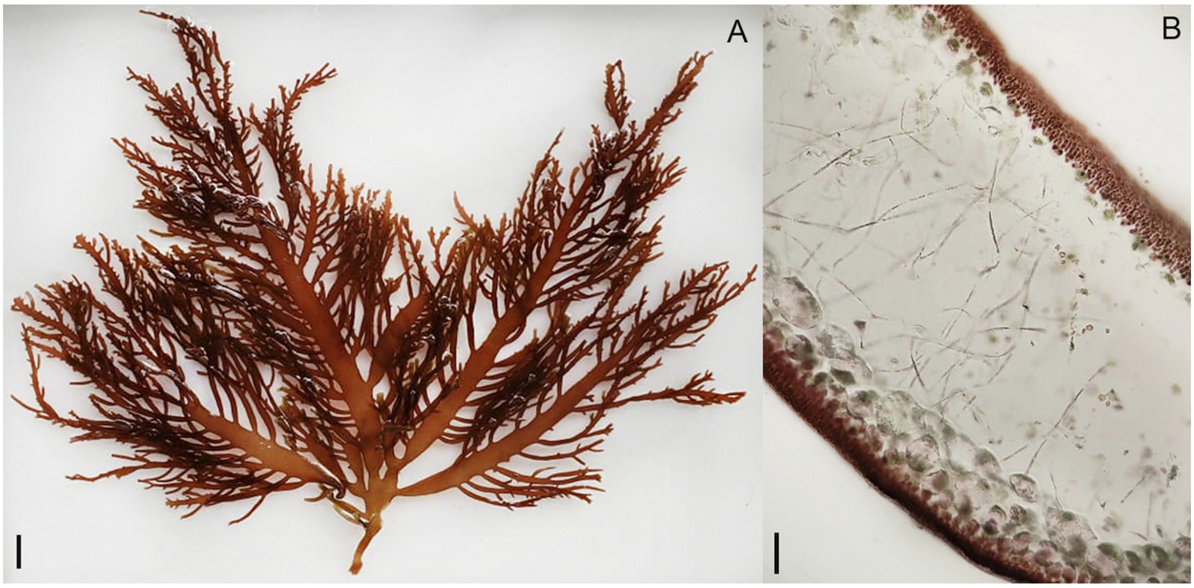

Figure 5. *Agardhiella ramosissima***.** A. General aspect of the thallus. B. Cross-section of the thallus. Scales: A=1 cm D=100 µm.

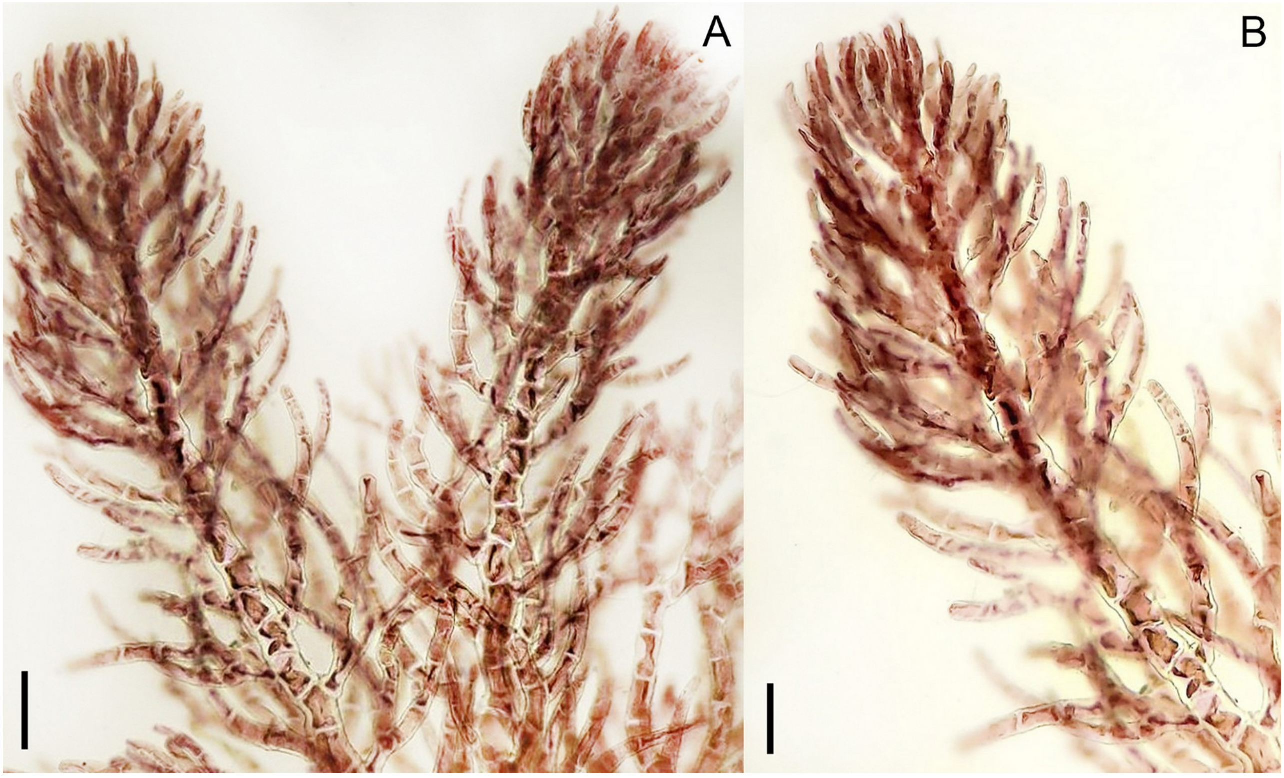

Figure 6. *Aglaothamnion felipponei*. A. General aspect of the thallus. B. Detail of the branching pattern and evident main axis. Scales: A-B= 100 µm.

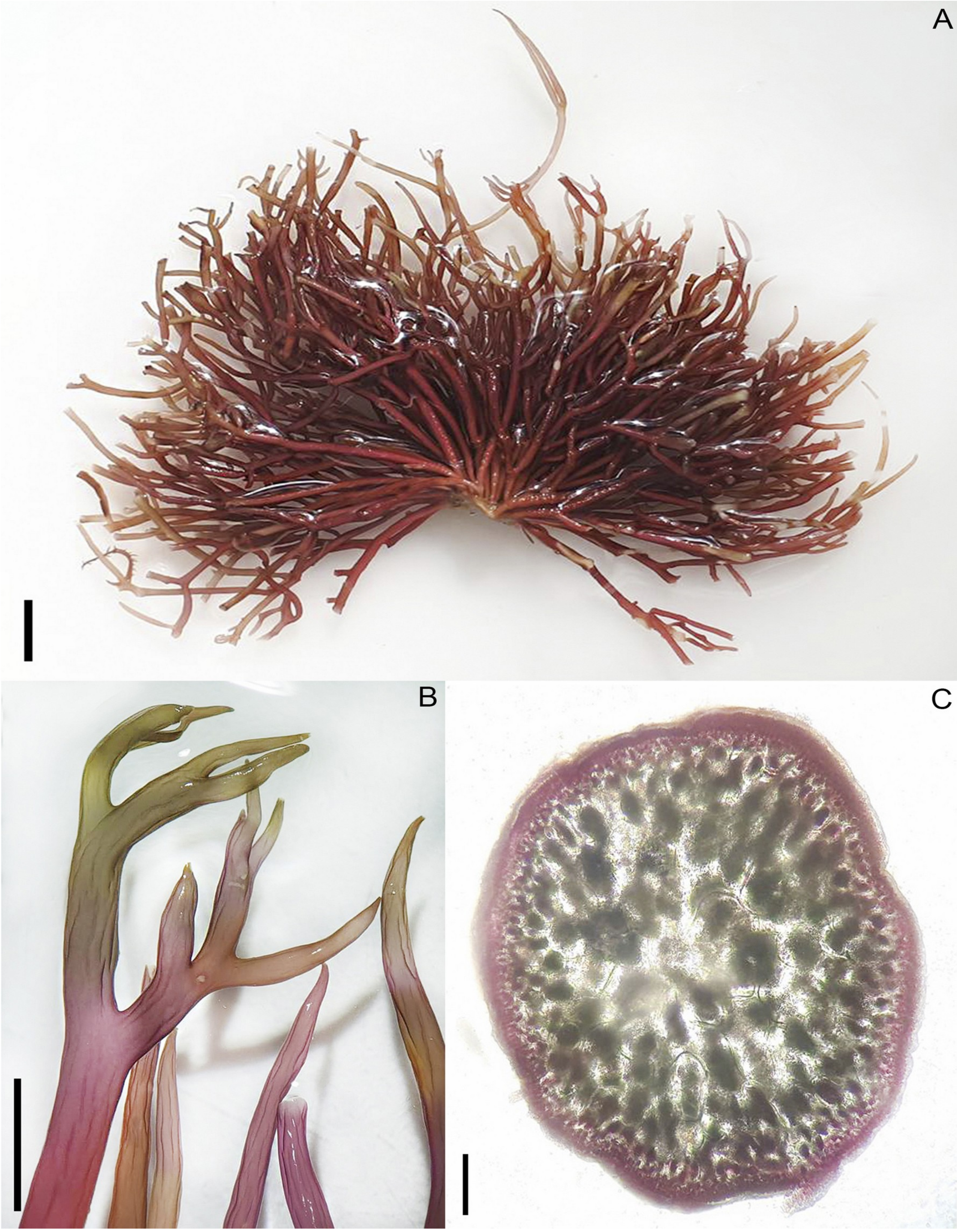

Figure 7. *Crassiphycus caudatus*. A. General aspect of the thallus. B. Detail of the Apice of the Branches. C. Cross-section of the thallus. Scales: A= 1 cm; B=0,5 cm; C=100 µm.

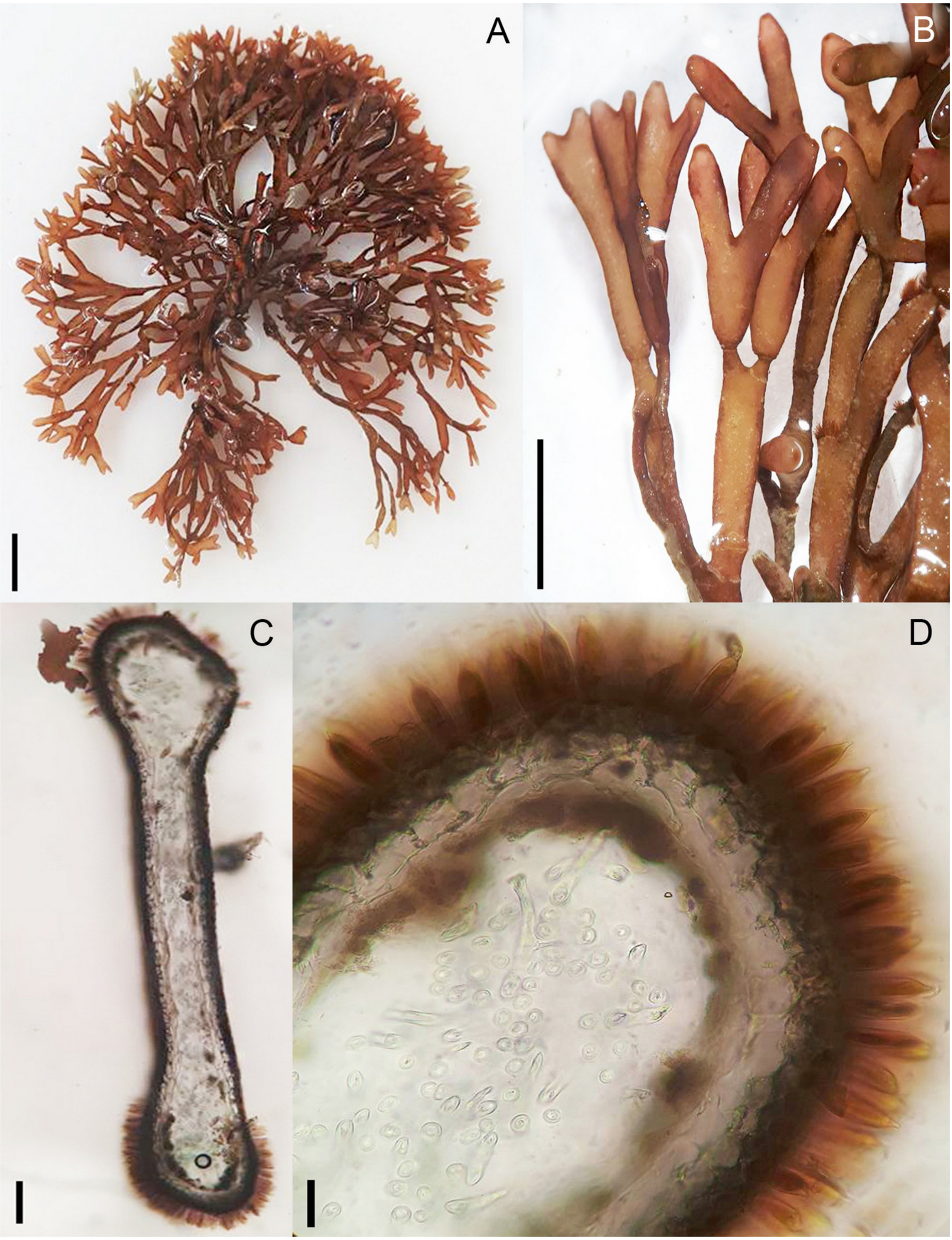

Figure 8. *Dichotomaria marginata.* A. General aspect of the thallus. B. Detail of the apex of the branches. C. Cross section of the gametophytic thallus. D. Detail of apiculate cells. Scales : A= 1 cm; B= 0,5 cm; C=100 μm; D= 25 μm.

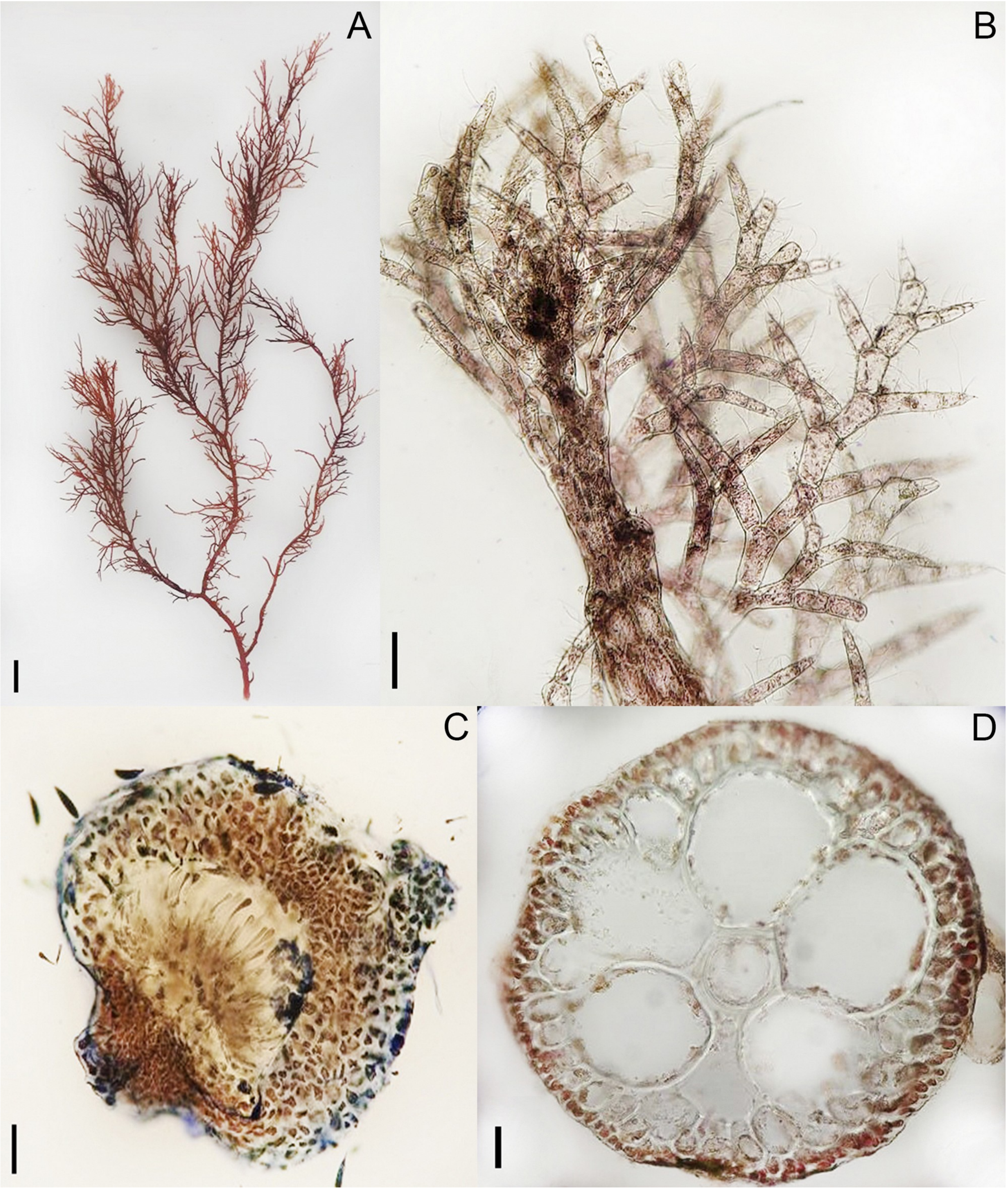

Figure 9. *Heterodasya mucronata*. A. General aspect of the thallus. B. Superficial view of the thallus with mucronate branchlets. C. Cystocarp. D. Cross-section of the thallus, showing 5 pericentral cells. Scales: A=1 cm; B-C=100 µm; D=25 µm.

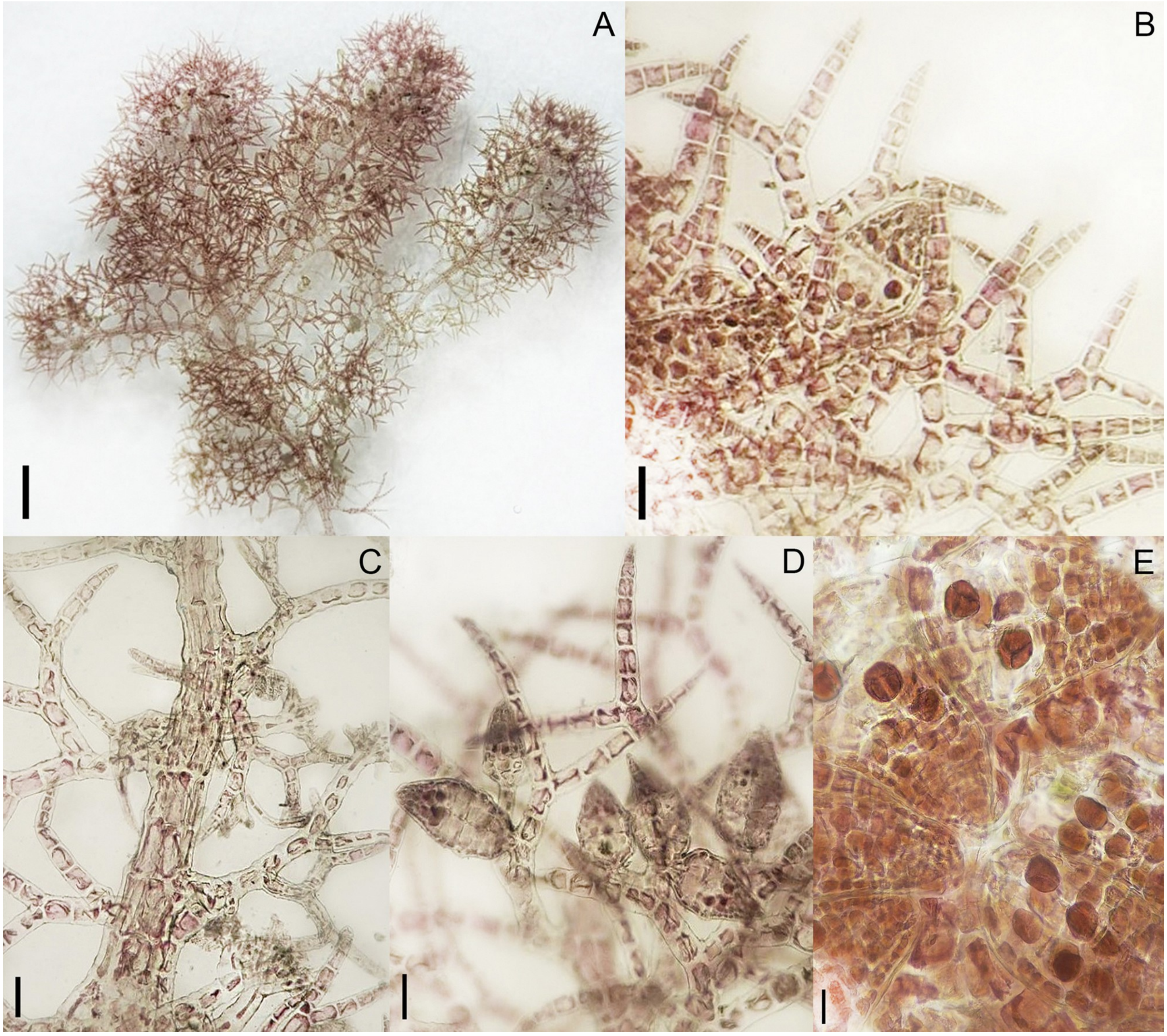

Figure 10. *Heterosiphonia crispella*. A. General aspect of the thallus. B. Superficial view of the thallus with acuminated apex and open-angle. C. Superficial view of the main axis. D-E. Superficial view of estiquidios and tetrasporangia. Scales: A=1 mm; B-C=100 μm; D-E=25 μm.

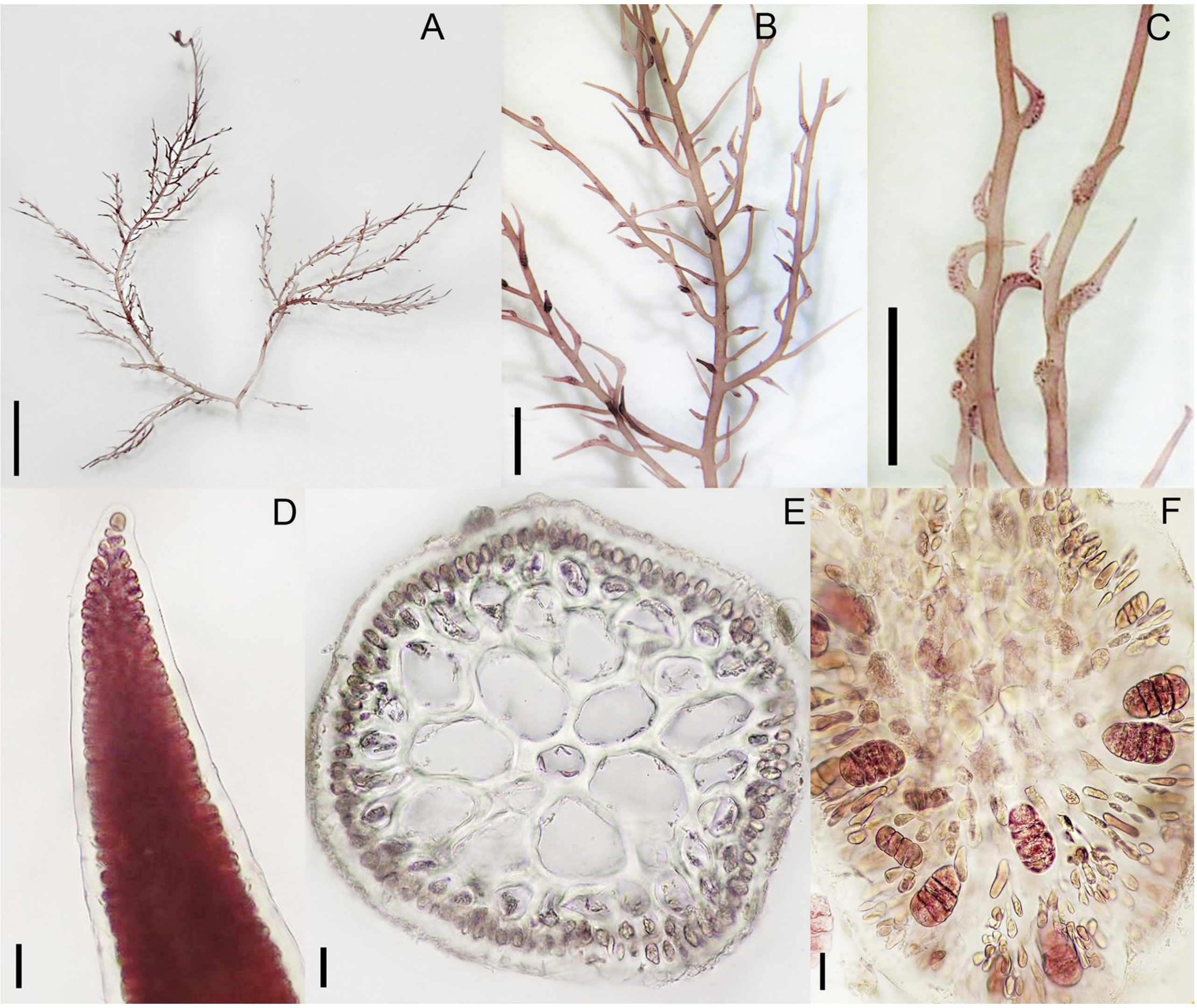

Figure 11. *Hypnea cornuta*. A. General aspect of the thallus. B. Detail of the branch. C. Superficial view of the branches with the arrangement of tetrasporangia. D. Superficial view of the apical cell. E. Cross-section of the thallus. D. Zoned tetrasporangia. Scales: A=1 cm; B-C=0,2 cm; D=100 µm; E-F=25 µm.

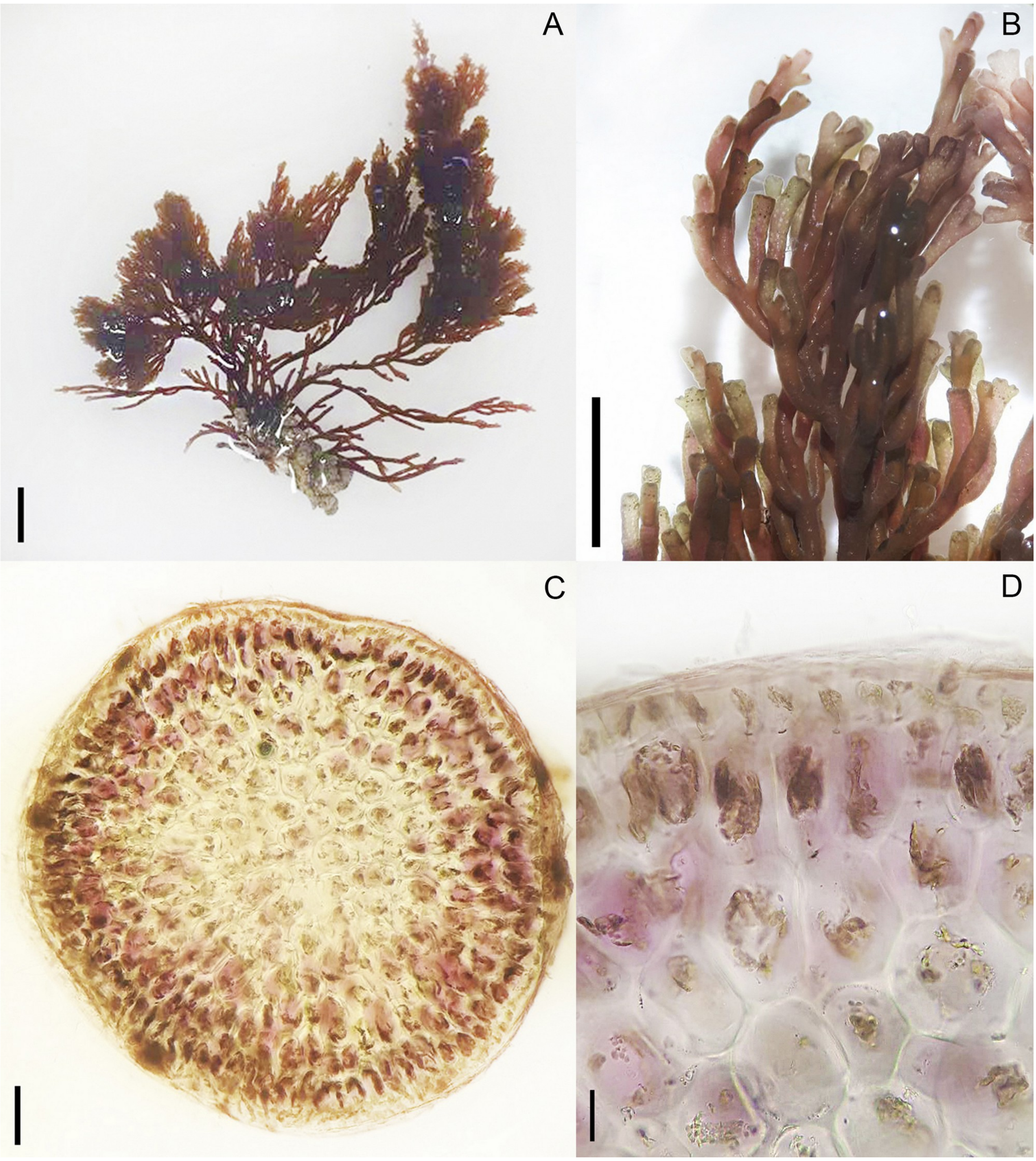

Figure 12. *Laurencia translucida*. A. General aspect of the thallus. B. Detail of the thallus branch. C. cross-section of the thallus, showing translucent cortical cells. D. Detail of the cross-section of the thallus, showing the cortex. Scale: A= 1 cm; B=0,5 cm; C=100 µm; D=25 µm.

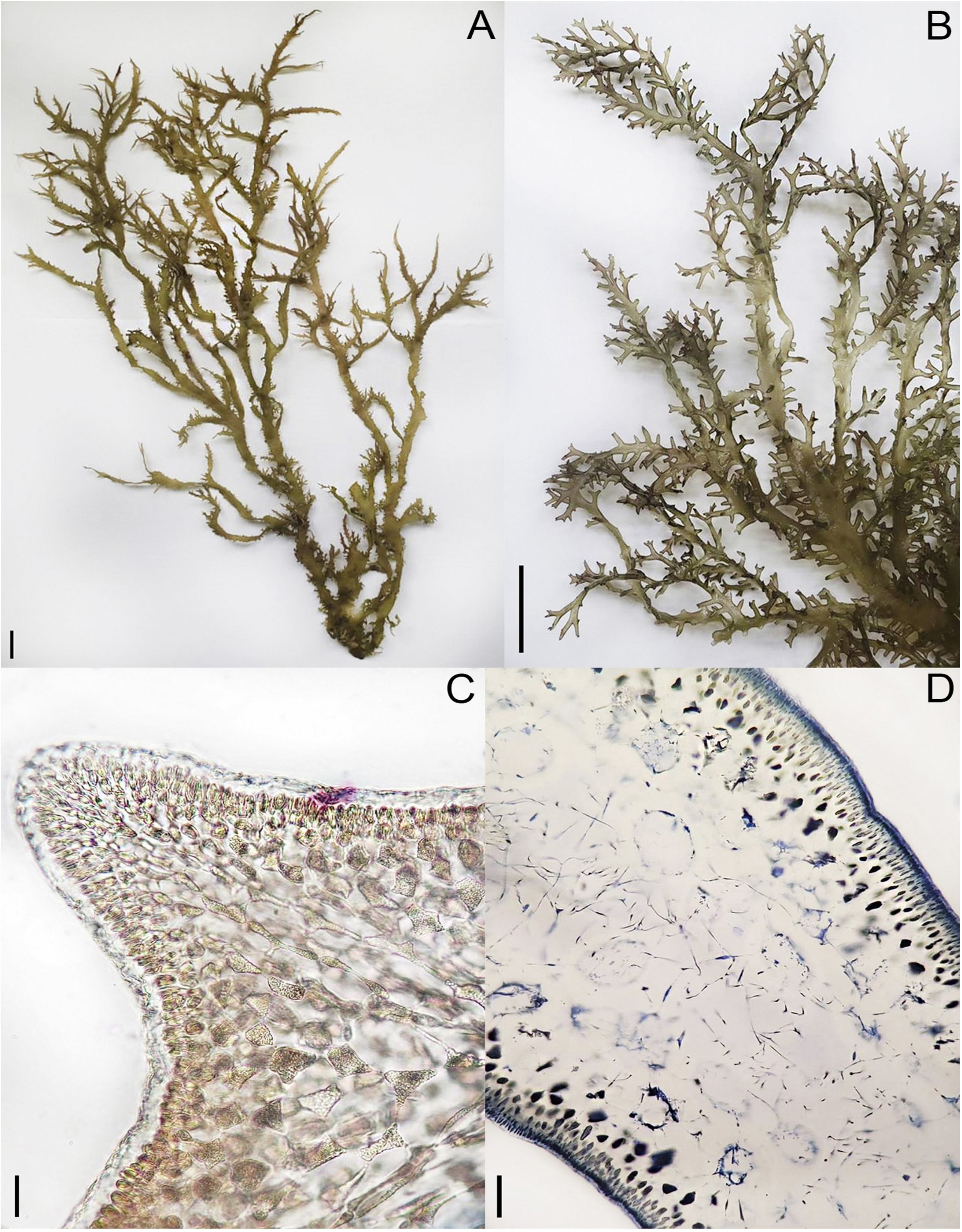

Figure 13. *Meristotheca gelidium*. A. General aspect of the thallus. B. Detail of the Cystocarpic branches. C. Longitudinal section of the apex. D. Cross-section of the thallus. Scale: A-B= 2 cm; C-D=100 µm.

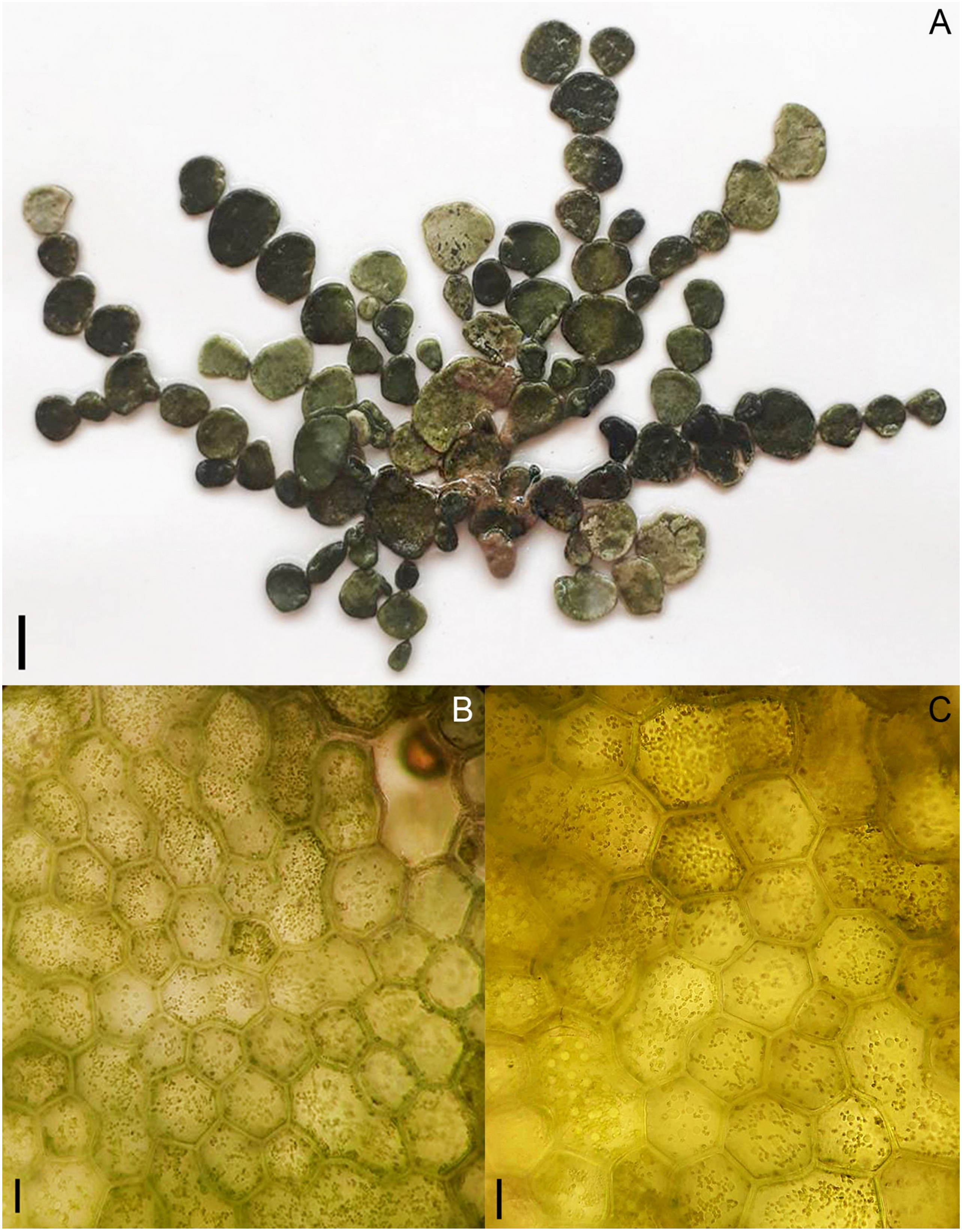

Figure 14. *Halimeda jolyana*. A. General aspect of the tallus. B-C. Superficial view of the thallus, a polygonal and hexagonal pattern of the utricles. Scales: A=1 cm; B-C=25 μm.

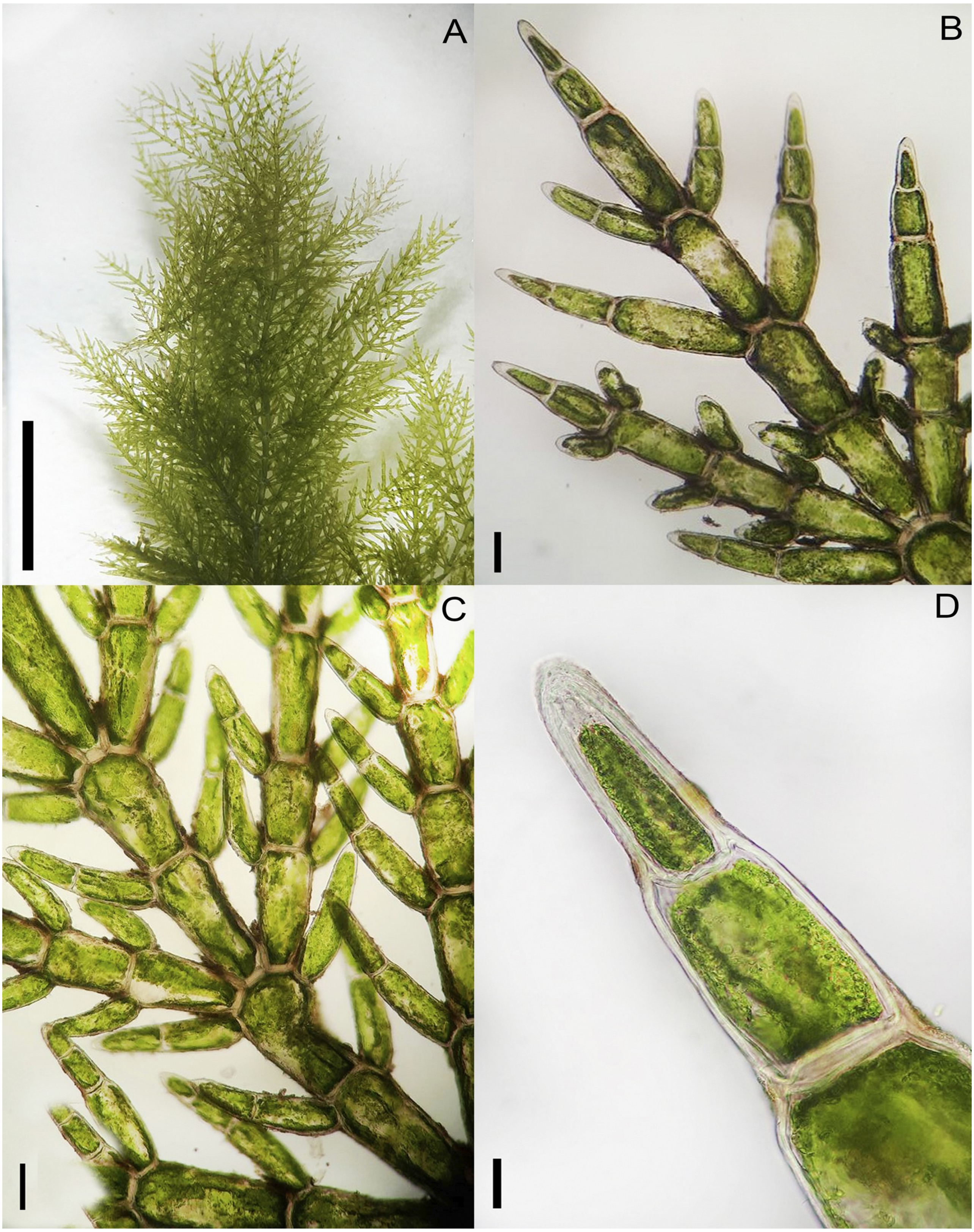

Figure 15. *Willeella ordinata*. A. General aspect of the thallus. B. Detail of the pinnate appearance of the branch. C. Branch detail in one plane. D. Detail of the conical apical cell. Scales: A=0,5 cm; B-C=100 µm; D=25 µm.